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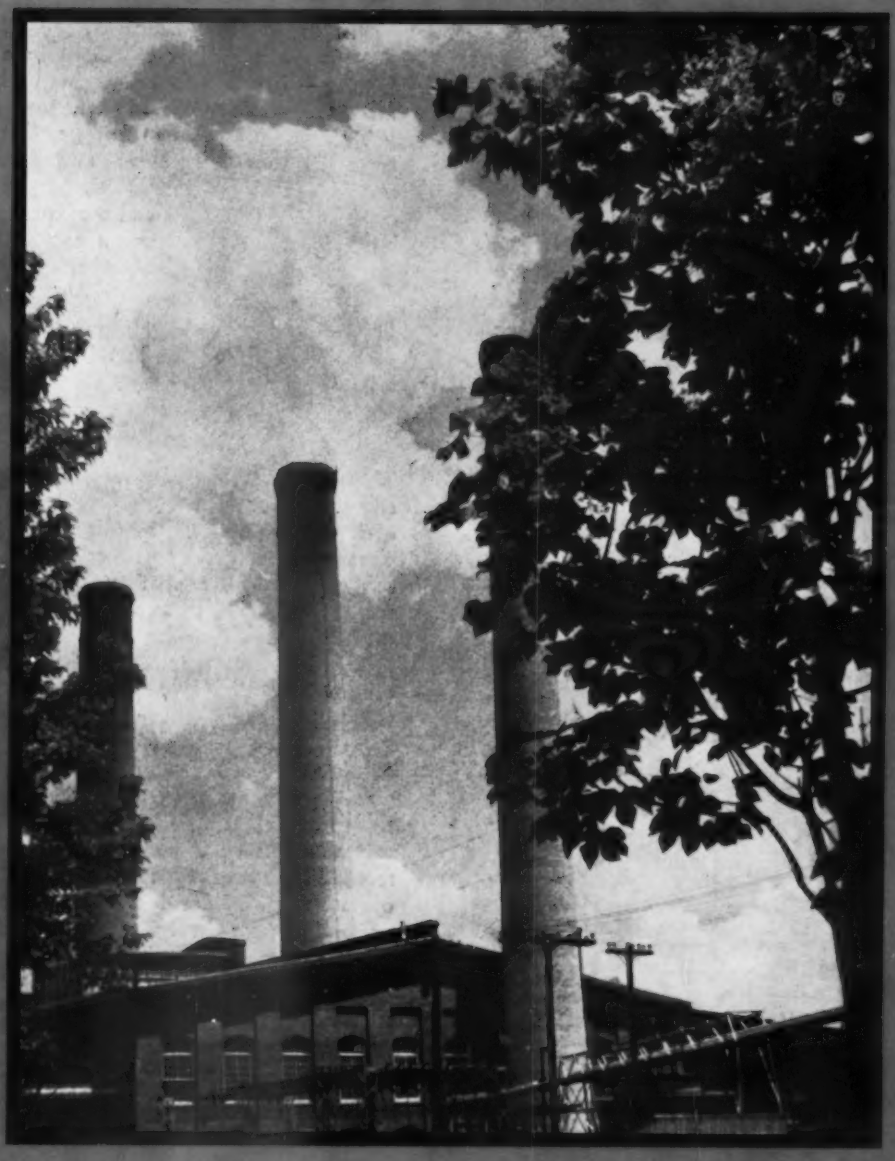
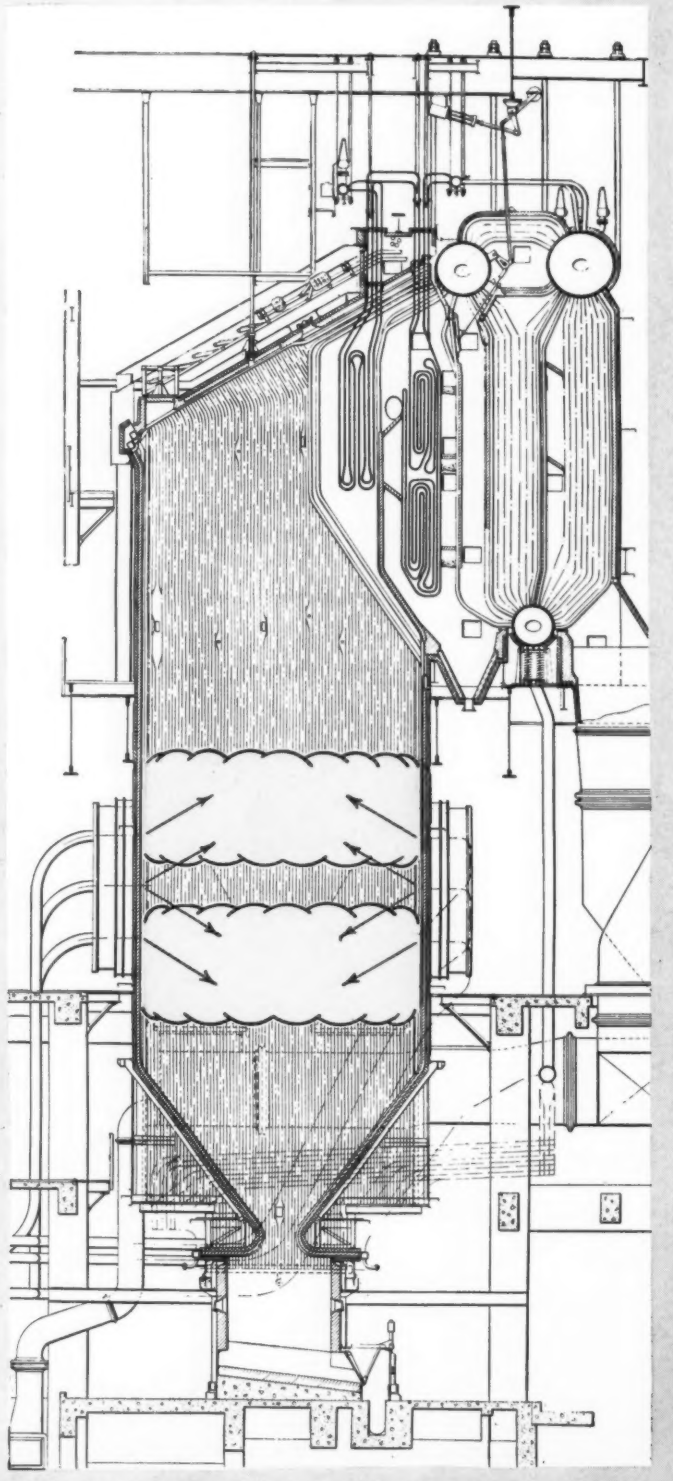


Tilting Burners Provide Flexible Furnace Performance ▶

Factors Affecting the Economic Selection of Steam Generating Equipment ▶

TANGENTIAL FIRING + ADJUSTABLE BURNERS = 6 IMPORTANT ADVANTAGES



C-E Steam Generating Unit equipped for tangential firing with C-E Vertically Adjustable Burners. Colored bands show diagrammatically how the position of the flame body can be controlled.

TURBULENCE — the most important factor in obtaining complete and rapid combustion in a pulverized fuel fired furnace — is most effectively achieved by the impingement of flame streams upon one another.

Tangential (or corner) firing, to a much greater extent than any other method, produces this ideal condition in a furnace. Intensive mixing occurs which facilitates the combination of combustible and oxygen and promotes rapid and complete combustion. At the same time a rotative or cyclonic motion is imparted to the flame body which:

1. Results in a longer flame travel.
2. Causes the hot gases to spread out and fill the furnace.
3. Provides a sweeping action that assures effective contact of the gases with all furnace wall surfaces.

These effects assure ample time for flame propagation with efficient combustion and low carbon loss, complete utilization of furnace volume and effective transfer of heat to the water walls by convection as well as by radiation. Collectively they account for the higher heat transfer rates and lower furnace exit gas temperatures which characterize the tangentially fired furnace.

When to these basic advantages of tangential firing is added the ability to direct and control the position of the flame body within the furnace, other equally important results are achieved. By means of vertically adjustable nozzles, operated by remote control, the operator can raise or lower his flame zone roughly as indicated by the illustration at the left. Thus adjustable burners provide, in effect, an "adjustable furnace" in that the furnace volume and furnace absorption surfaces can be adjusted to the requirements of any grade of coal delivered to the plant. Actual operating experience has demonstrated that this feature is responsible for several very desirable effects among which the following are the more important:

(1) The temperature at the top of the furnace can be varied from 100 to 150 degrees and by this means a primary control of steam temperature is obtained.

(2) Water wall surface may be employed most effectively for various conditions of operation by the ability to bring more or less of it into the active zone at will.

(3) The ability to vary furnace exit gas temperatures permits substantial control over slagging conditions by providing a means of preventing the ash leaving the furnace from reaching the plastic stage.

Thus the combination of tangential firing and vertically adjustable burners not only provides all of the requisites for efficient combustion and heat absorption but also aids materially in meeting the difficult problem of controlling steam temperature.

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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME SIXTEEN NUMBER TWELVE

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ALFRED D. BLAKE, *Editor*

THOMAS E. HANLEY, *Circulation Manager*

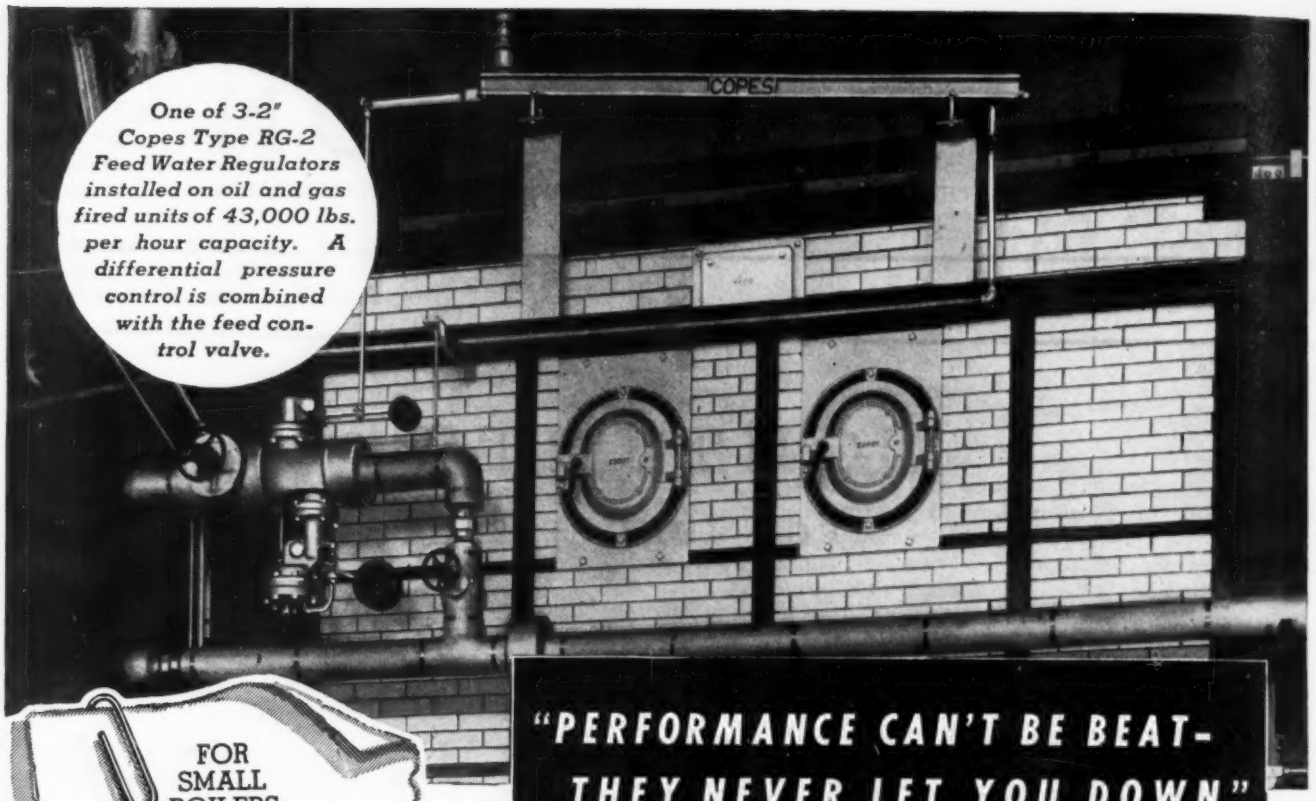
Published monthly by COMBUSTION PUBLISHING COMPANY, INC., 200 Madison Ave., New York 16
A SUBSIDIARY OF COMBUSTION ENGINEERING COMPANY, INC.

Frederic A. Schaff, President; Charles McDonough, Vice-President; H. H. Berry, Secretary and Treasurer.

COMBUSTION is sent gratis to engineers in charge of steam plants from 500 rated boiler horsepower up and to consulting and designing engineers in this field. To others the subscription rate, including postage, is $2 in the United States, $2.50 in Canada and Great Britain and $3 in other countries. Single copies: 25 cents.
Copyright, 1945 by Combustion Publishing Company, Inc.
Issued the middle of the month of publication.

Publication office, 200 Madison Ave., New York Member of the Controlled Circulation Audit, Inc.

Printed in U. S. A.



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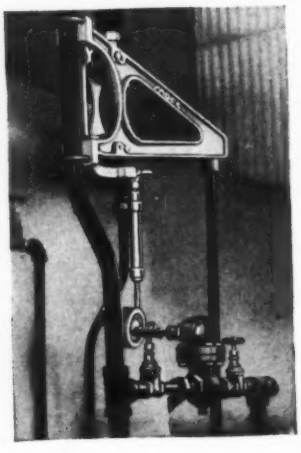

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EDITORIAL

Post-War Materials

It will be recalled that following World War I, considerable difficulty was experienced in procuring materials that consistently fulfilled expectations as to specifications, and certain failures, such as in turbine disks, resulted.

At the recent meeting of the National Board of Boiler and Pressure Vessel Inspectors, H. B. Oatley, Chairman of the A.S.M.E. Boiler Code Committee, sounded a note of warning lest the reconversion period experience a recurrence of such conditions. In fact, the possibilities are even greater this time because of the extensive use of various alloys in war production. Vast quantities of scrap from war matériel will likely find their way back to the steel mills and it will be impossible adequately to identify, sort and label all such scrap, despite attempts at control. The inclusion of even small excesses of certain elements have a considerable influence on the physical characteristics of the finished product.

Also, the war has brought about marked advances in metallurgy, the full extent of which will not be generally revealed until the exigencies of the present conflict are past. Many of these alloys have been developed and adapted to meet specific purposes, but their general application to other uses must await trial and close observation under varying conditions peculiar to such uses. Hence, no immediate change in practice as concerns power plant materials can be anticipated, other than a possible continued use of certain substitutes occasioned by war expediency which may have proved their worth. These, however, do not concern stressed parts.

Thus the warning voiced by Mr. Oatley is most timely and should serve to stimulate extra precautions in the post-war period.

Coal Stockpiling

Both the Solid Fuels Administration and Chairman Krug of WPB have urged users to stock up on coal during the summer months as an insurance against a critical fuel shortage next fall and winter, and thus ameliorate the effects of the present deficit in coal production which is estimated to reach some 25 million tons for the current year. This deficit has been due both to manpower shortage at the mines and to interruptions in production during the past spring when it also became necessary to deplete stocks held by users.

The character of the coal industry, unlike many other industries, is such that storage at the mines is impracticable; and users, by ordering now for stockpiles, will aid in keeping the mines running at full output during the summer. Morever, deliveries made during this season by rail and water are not affected by adverse weather conditions.

This request appears logical but, unfortunately, some coals cannot be stored without deterioration and danger of spontaneous combustion. This applies particularly to some of the coals that now happen to be most procurable. Moreover, all users do not have facilities for large storage.

However, where at all feasible, users would do well to heed the advice of Mr. Krug and the Solid Fuels Administration. The money tied up will be well-warranted insurance against grief later in the year such as was experienced in many sections of the country last winter.

New Installations Get Government Approval

In line with the recently announced purpose of WPB to relinquish production restrictions as speedily as possible, consistent with present war requirements, comes an announcement from Washington that the Office of War Utilities has just given the green light on nearly half a million kilowatts of steam turbine-generator capacity for installation during the next two years. In practically all cases steam-generating units are also involved. The approved installations cover units of a wide range in capacity for both private utilities and municipal plants, and largely concern extensions to existing stations rather than new stations. Some previous releases had been given during the past few months, orders for which have already been placed, and further releases are expected shortly. Hence, an active period in the power plant field may be anticipated.

During the construction holiday of the last three or four years, few major changes have taken place in stationary power plant practice; but there have been many refinements in design, dictated by operating experience and advances in manufacturing technique. This is particularly true of steam-generating units. As these plants are extended, the new units will obviously incorporate these refinements and in some cases changes to meet changed fuel conditions. Therefore, there will be few, if any, actual duplicates of existing large units installed in the immediate pre-war period, regardless of how excellent their performance may have been.

As for the turbine-generators, these are expected to conform in most cases to the recently approved preferred A.S.M.E.—A.I.E.E. Standards as to capacities as well as steam and extraction conditions.

Tilting Burners Provide Flexible Furnace Performance

Control of exit furnace gas temperatures is most important as a means of preventing excessive slag deposits at the entrance to the convection heating surface and to assist in controlling superheat temperature over a wide range in load. How this is effected by tilting tangential burners upward or downward through a total arc of approximately 60 deg is described, and typical performance curves derived from tests are included.

By ELNO M. POWELL

Combustion Engineering Company, Inc.

THE most difficult problems facing the designer of a pulverized-coal-fired steam generating unit today are proportioning the furnace and superheater and providing the desired superheat control. During the last ten years the use of high steam temperature and pressure has become firmly established in the larger utility and industrial power plants. There is little question that still higher steam temperatures can be expected in the future as better materials become available. At the same time constant steam temperature will be desired over a wide range of loads to aid in the turbine design and maintain a high station efficiency.

These problems are aggravated by the quality of the coals now available for steam generation which has rapidly become worse during the war, particularly on the Eastern Seaboard. The fusion temperature of the ash of the average coal today is lower and the quantity of ash has increased with the increased application of mechanization in mining operations. The coal industry has warned that this trend will continue and, in addition, premium low-volatile coals eventually may be withheld from power stations and used exclusively for metallurgical purposes.

With the conventional types of burners and pulverized-coal furnaces where the heat is released in one fixed zone, the temperature of the gases leaving the furnace will vary with the rate of firing. Until recently there has been no practicable means for changing this gas tem-

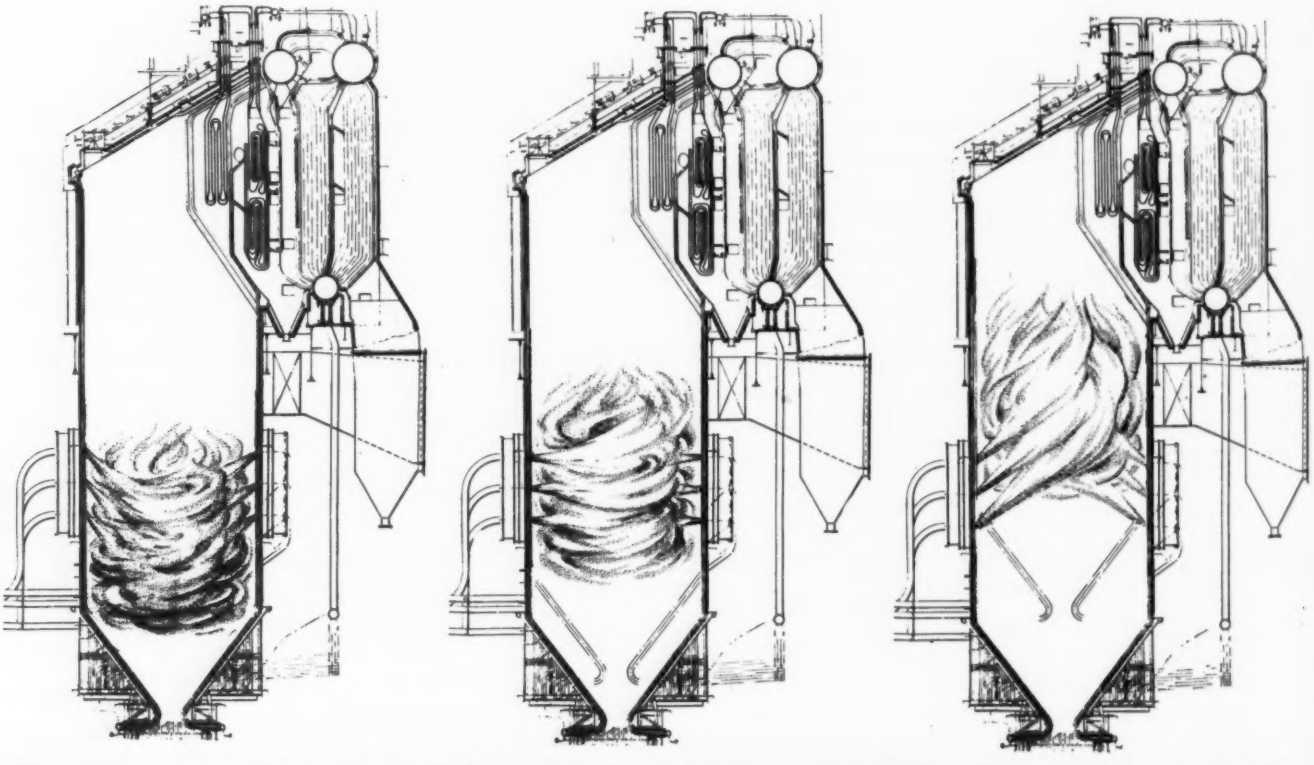


Fig. 1—Three views of typical tangentially-fired furnace showing burner positions: tilted, 30 deg downward, horizontal, and 30 deg upward respectively

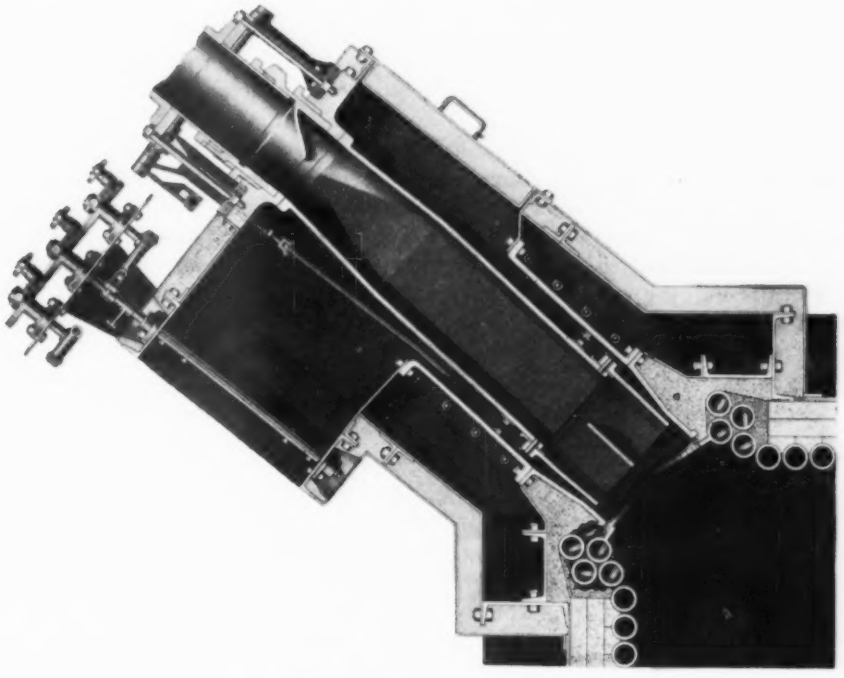


Fig. 2—(top) Plan of tilting tangential burner

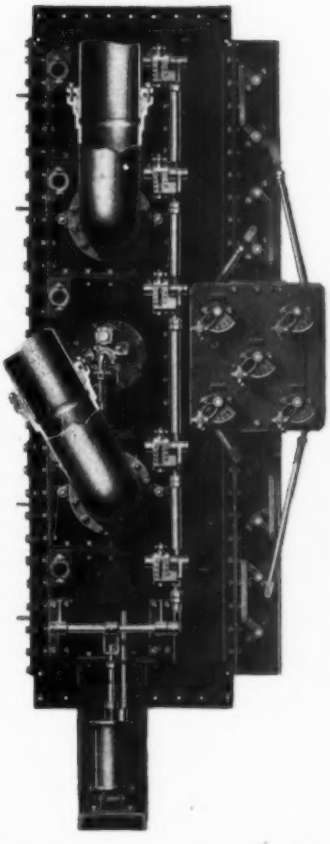


Fig. 3—Front view of tilting burner, showing operating mechanism

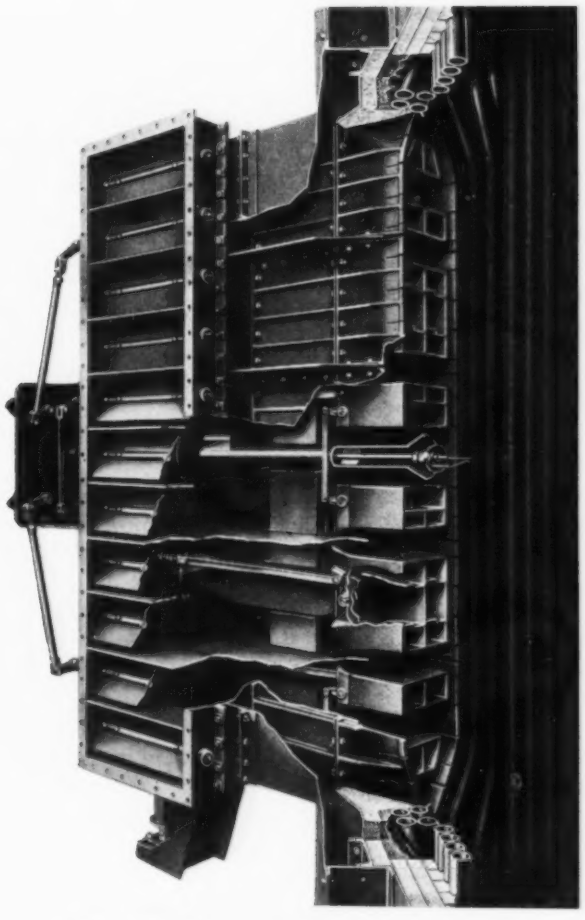


Fig. 4—Side perspective of tilting burner

perature characteristic, once established by the furnace design, without changing the distribution of fuel delivered to the several burners or by varying the number of burners in operation. Such procedures require increased firing capacity or a duplication of equipment and are a burden to the operating personnel, particularly if frequent changes are required.

Specifically, the two main problems confronting the designer of a steam generating unit are to provide sufficient volume and heat-absorbing surface in the furnace to reduce the temperature of the gases entering the convection heating surfaces of the unit to such a point that the slag and ash deposits may be easily controlled and at the same time to provide sufficient gas temperature entering the superheater to obtain the desired steam temperature at some reduced load known as the *control point.*

For example, when heating steam to the present high temperature of 950 F at a pressure of 1400 psi, there is a definite quantity of heat absorption required per pound of steam of approximately 290 Btu. With a superheater which absorbs heat by convection this heat must come from the gases passing over the superheater of which there is a definite weight per pound of steam of approximately 1.2. Each pound of gas must then give up 240 Btu which corresponds to a drop in gas temperature of 860 F.

Limits for Furnace Exit Gas Temperature

A convection superheater with the highest efficiency is one designed so that the products of combustion flow counter to the flow of steam thereby permitting the gases to be cooled to a temperature below that of the steam leaving the unit. For a practicable or economical design of such a unit operating at around 1400 psi it is preferable to limit the exit gas temperature leaving the superheater to not less than 800 F at the control point. This establishes 1660 F as the minimum gas temperature entering the superheater. Add to this the gas temperature drop across the screen tubes in front of the superheater and the required gas temperature leaving the furnace becomes 1900 F, even at the lowest load for which 950 F steam has been specified. This approaches very closely the fusion temperature of many available coals and will exceed it as the boiler output is increased. Higher steam temperatures will, of course, require still higher gas temperatures.

The problem of furnace and superheater design then resolves into a compromise between high gas temperatures at maximum capacity with the danger of excessive slag accumulation or low steam temperature at reduced load which would limit the range of loads over which a constant superheat could be maintained. When the gas temperature characteristic of a furnace cannot be conveniently varied, the designer is limited in his ability to meet the demands of the users. Therefore, a means for varying the desired efficiency of heat absorption in the furnace so as to increase the temperature of the gases to the superheater at lower loads and limit it at higher loads is most desirable.

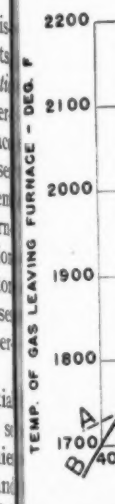
A number of schemes have been used in the past for accomplishing this, such as the use of auxiliary burners, a combination of large and small superheaters, a combination of radiant and convection superheaters, double furnaces, or by changing the proportion of fuel supplied to individual burners. All of these have attendant disadvantages of higher cost, greater space requirements or complication of operation and control. One *fantastic* solution to the problem would be to screen the water wall surfaces with venetian blinds so that all of the surface could be exposed to radiant heat at high loads and lesser amounts as the load decreased. However, a recent development in the design and arrangement of the burners for tangential firing has permitted the same variation of effective heating surface merely by pressing a button or turning a knob on the operating board which raises or lowers the direction of the coal and air streams entering the furnace.

A detailed discussion of the principles of tangential firing will not be given here because it has been used so extensively by the utility and large industrial companies for many years. Fundamentally, however, the coal and air are divided into several relatively small streams which are directed from the four corners of the furnace tangent to a small circle in the center. No attempt is made to mix the coal and air in the burners except to provide sufficient primary air with the coal stream to obtain ignition. The cyclonic or rotative motion within the furnace resulting from the impingement of streams upon one another produces the turbulence and mixing of fuels and air necessary for rapid and complete combustion of the fuel. Because of the long flame travel in the horizontal plane, combustion is completed within a comparatively short vertical distance. This releases nearly all of the heat from the fuel in the zone of the burners so that it is available for radiant absorption by the maximum amount of water-wall surface present.

When the coal and air streams are directed downward toward the furnace hopper the rate of heat absorption by the heating surface located in the lower furnace will be increased. Furthermore, combustion will be completed at a point lower down in the furnace, thereby improving the efficiency of the upper water-wall surface which, in turn, will result in a lower temperature of the gases leaving the furnace. Exactly the opposite effect will result from directing the coal and air upward, thus using the lower part of the furnace less effectively and forcing the flame closer to the top of the furnace which results in less time for heat absorption and a higher gas temperature leaving the furnace.

The three illustrations in Fig. 1 show the shape of the flame and active combustion zones for three burner positions: tilted 30 deg downward, horizontal, and 30 deg upward, respectively. The dash-lined furnace hopper for the horizontal and upward burner positions are intended to show figuratively the boundary of the effective part of the furnace. Conceived in this manner the furnace becomes adjustable, meaning that the effective heating surface may be adjusted to meet the load and the gas temperature requirement. In order to realize the maximum temperature variation with tilting burners, they should be located sufficiently high above the hopper so that a full tilt downward may be used without excessive impingement on the sloping sides of the hopper. Sufficient height above the burners should also be provided so that there will be no direct flame impingement on the screen tubes in front of the superheater.

The details of the burner design are shown in Figs. 2, 3 and 4 which represent plan, front and side perspective, respectively. Adjustable tips are pivoted to the ends



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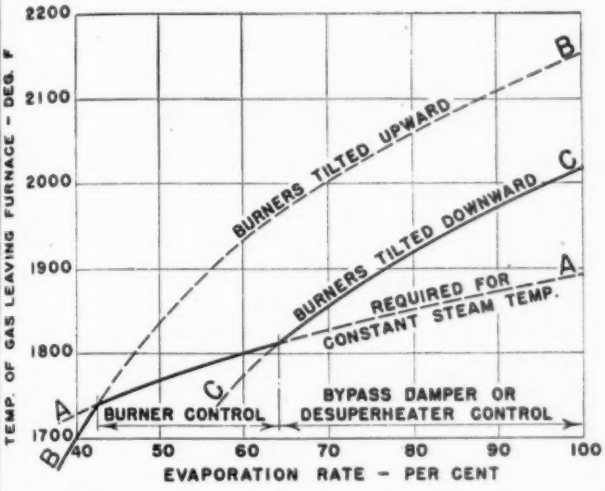

Fig. 5—Performance curves for furnace designed to provide desired gas temperature at 65 per cent load with burners tilted downward

of the coal nozzles and adjustable guide vanes are located in the air ports. Individual operating rods are carried through the burner front where they are linked together and operated simultaneously as a unit. The prime mover may be a handwheel, motor or pneumatic cylinder. Fig. 3 illustrates the application of the pneumatic cylinder. The motor or the cylinder may be operated manually by remote control or automatically by the steam-temperature control.

Changing the direction of both the coal and air streams insures positive control over the direction and positioning of the flame and maintains the same principle of combustion which characterizes tangential firing. Recent tests have shown that tilting the burners has little effect on the unburned combustible in the fly ash.

The first burners of this design were placed in operation about three years ago with others following shortly after. To date there has been no boiler shutdowns attributable to failure of burner parts, nor has there been any evidence of increased burner maintenance.

The full significance of an adjustable furnace may be best appreciated by a discussion of specific furnaces the performance of which is given in Figs. 5 and 6. Curve A-A in both cases represents the temperature of the gases having the furnace as required by a counter flow, convection superheater in order to maintain a constant steam temperature of 935 F. The same superheater is assumed for both cases.

Fig. 5 illustrates the performance of a furnace selected so as to provide the gas temperature required by the superheater for the specified steam temperature at approximately 65 per cent of maximum load with the burners tilted downward. The steam temperature at higher loads must then be controlled with a bypass damper or desuperheater. The range of constant superheat from 65 per cent to maximum load corresponds approximately to that normally obtained with a conventional steam generating unit. Curves B-B and C-C indicate the approximate limits between which the gas temperature may be varied by tilting the burners through an angle of 50 deg. The solid portion of the three curves indicates the normal variation of gas temperature with rating when the burners are adjusted to provide the widest possible range of load with a constant steam temperature. It will be noted that the solid line falls below Curve A-A at ratings below 43 per cent indicating insufficient gas temperature for constant superheat. The control point with tilting burners then becomes 43 instead of 65 per cent with the conventional unit mentioned above. If a furnace were to be selected for the same range of control without tilting burners the gas temperature characteristic would be similar to Curve B-B. The gas temperature at full load would be about 2150 F which exceeds the fusion temperature of many of the coals fired today. Obviously, the operating cost required for removing slag deposits would be higher.

Fig. 6 shows the performance characteristics of a larger furnace followed by the same superheater that was used in the previous example. In this case the heating surface in the furnace was increased so that the exit gas temperature at maximum load would coincide with Curve A-A. Tilting the burners upward as the load is reduced will provide sufficient gas temperature for the specified steam temperature down to approximately 65 per cent of capacity which is essentially the same degree of steam temperature control as can be obtained with the conventional unit. A bypass damper is unnecessary with such a selection of equipment with normal cleanliness of the water walls, excepting as a precautionary measure to allow for increased dirtiness resulting from the use of other coals than that contemplated or for other unforeseen contingencies. Excepting the control point, the gas temperature leaving the furnace is considerably lower at all loads than indicated by the solid line in Fig. 5 and the maximum does not exceed 1900 F. Such a furnace would be suited to any coal. The increased furnace surface required is considerable, however, and the higher cost could only be justified in those instances when sustained high loads and poor coals are anticipated.

All of the above discussion applies to dry-bottom furnaces. The performance characteristic of wet-bottom furnaces will be somewhat different since sufficient heat must be present at the floor at all times in order to maintain the slag in a molten state for continuous removal. By arranging the burners in two groups, one of which is located higher up in the furnace, most of the features of the adjustable furnace may be retained without destroying the ability to melt the slag. At the same time local concentration of heat usually found in wet-bottom furnaces will be greatly reduced.

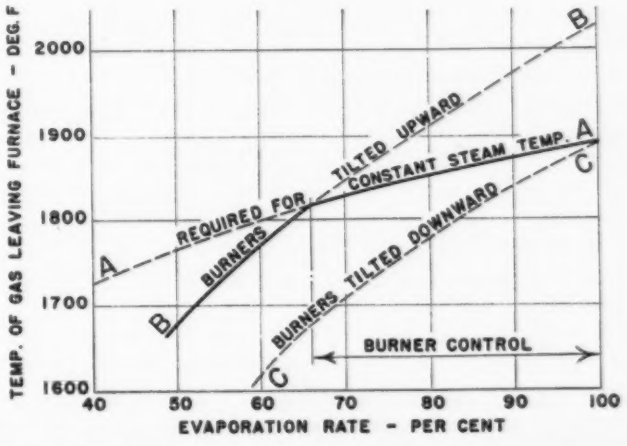

Fig. 6—Performance curves for larger furnace and same superheater as in Fig. 5

Factors Affecting the Economic Selection of Steam-Generating Equipment

By FRANK S. CLARK

Consulting Engineer, Stone & Webster Engineering Corporation

THE writer remembers the time well over twenty-five years ago when, at the beginning of a year the representatives of a certain boiler and of a superheater manufacturer would come to the office and close contracts for the estimated boiler and superheater requirements for the year. Boilers at that time were usually for 200 psi, twenty-one sections wide and fourteen tubes high; but water-tube boilers then were in the minority. The total steam temperature was around 525 F. Selection of steam-generating equipment was as simple as that.

Conditions have changed radically since those days and so many factors enter into the selection of modern steam-generating equipment that their proper evaluation is one of the most important features of present-day power plant engineering. These factors may be divided into two classes, namely, those imposed by the uses to which the steam is to be put and the fuel available, and those applying to the type of equipment best suited to meet the particular conditions imposed.

This is a general discussion of various factors that must be taken into account when selecting a steam-generating unit to meet given conditions, as viewed from the standpoint of the consulting engineer. No attempt has been made to go into details, but rather to review the economic considerations.

Two Pressure Groups

In the former class are the operating pressure and temperature. In the steam-electric generating station, these have increased as the materials available permitted, and for the present are divided into the 800–900 psi, 850–900 F and the 1200–1400 psi, 900–950 F groups. The lower range group has been adopted, with some exceptions, where the turbines are straight condensing, using the regenerative cycle, and where no special or unusual conditions are to be met. The latter has been used principally in connection with superposed on "topping" turbines, but in some cases is employed with straight condensing units when high load factors or high fuel costs have made its adoption economical.

Character and treatment of feedwater play an important part in the selection of operating pressure and temperature, and in the design of the generating equipment, even when the percentage of makeup is as low as one per cent. Difficulties in treatment increase as pressures are raised and may be one of the reasons for the present-day preference for the 800–900-psi pressure range.

Influence of Fuels on Design

The character and types of fuels available and the desirability of being able to burn fuels of widely varying characteristics have a marked effect on the type of equipment selected as well as on its design. This is becoming increasingly important in view of the present fuel situation. Coals vary widely with locality, and in many cases gas and oil are available either as main or auxiliary fuels. The practically universal use of pulverized coal for firing large units means that whatever fuel is used it is burned in suspension and the furnace is designed with this in view. Coals vary greatly in their ash content and in the fusing temperature of the ash. Consequently, the heat input to the furnace and the absorption by its walls must be proportioned so that not only must combustion be completed before the gases leave the furnace but that their temperature be sufficiently below the fusing point of the ash to preclude the clogging of the exit passages from the furnace into the convection heat-absorbing surface. This latter condition has an effect on the amount of superheater surface that must be employed and its position in the unit.

Furnace temperature varies with the rate of heat input and absorption, and, along with fusion temperature of the ash, usually determines whether a wet or a dry bottom is to be employed. The former type will generally collect up to approximately 50 per cent of the ash of the coal on the bottom in molten form where it can be tapped out and thus decrease materially the amount to be collected by cinder and fly-ash eliminating equipment or the quantity discharged to the atmosphere. Its disadvantage is that, especially when the ash-fusion temperature is high, the rate of evaporation and therefore the furnace temperature must be such as to keep the ash in a molten state. The dry-bottom type of furnace, on the other hand, permits of lower rates of heat release and in general easier overall operating conditions, but would probably result in a larger furnace for the same conditions. A proper determination can only be made after all the facts are known and analyzed for each case, particularly as to load conditions and coal characteristics.

Steam Temperature Control

The water rate of steam turbines increases with decrease in total steam temperature. It is of advantage, therefore, to maintain constant temperature throughout a portion of the range of output of a steam generator below that at which it is rated. The degree to which it is economical to carry this depends upon the effect of reduced temperature on the efficiency of the turbine as compared with the additional cost of extra superheater surface that must be installed.

The heat-absorbing surfaces of steam-generating equipment consist of the water-cooled walls exposed to the radiant heat of the furnace, a varying amount of convection surface over which the gases pass, the superheater, in some instances an economizer, and the air heater. Their arrangement and heat-absorption rates vary with the conditions imposed and the ends to be achieved. There are many installations designed for operation at from 800 to 900 psi in which economizers are omitted and some at 1200 psi and higher. Economizer surface is less expensive than boiler surface and by their use it is possible to reduce the gas temperature to the air heater to less than the saturated steam temperature. Economizer surface, however, under some conditions is susceptible to sludge and scale deposits and may be difficult if not impossible to clean except by employing acid treatment which necessitates taking the unit out of service.

The efficiencies of modern steam-generating units range usually from 85 to 90 per cent, the latter figure being the upper economic limit. Affecting the efficiency to be desired are investment cost, cost of fuel, load factor, and exit gas temperature. Each point added to efficiency is attained at increasingly greater investment cost. Moreover, if the exit gas temperatures approach too near the dew-point, corrosion of the air heater elements will likely occur.

The upper drum of a modern steam generator may be 90 ft or more above the bottom floor. With the heat-absorbing surfaces arranged in this manner a minimum of ground surface is occupied but the supporting structure becomes extremely high and loads that must be supported on the foundations sometimes become excessive. An alternative to this, where ground space is available, is to reduce the height to a point sufficient to maintain proper circulation and spread the surface out by using an idle pass or some other arrangement.

Feedwater Treatment for High Pressures

The treatment of the makeup water becomes of increasing importance as pressures increase above 400 psi, particularly when the makeup is a large percentage of the steam generated, as in plants using steam for processes. Even in condensing stations sufficient solids, both soluble and insoluble, may be carried over into the turbine to cause loss in capacity and require frequent shutdown for cleaning, unless care is taken in the treatment of the water and in the design of the boiler internals to insure the delivery of clean steam.

In the case of a high percentage of makeup, furnace design should be such as to insure low rates of heat input to the furnace and of absorption by the furnace wall. Moisture-separating devices should be of a design that will not clog with sludge formations.

A novel design of steam generator, as yet untried, divides the steam generation into two parts; the first consisting entirely of radiant surface and the second being entirely convection. The latter is fed with water from the drum of the first or radiant section. Blowdown is entirely from the second section, which permits of lower concentrations being carried in the radiant portion where sludge formations are most likely to cause trouble.

There is installed in the Somerset Station of the Montaup Electric Company, a high-pressure forced-circulation steam generator, the first of its type in this country. Certain very definite factors influenced its selection. It was to be installed in an existing building in the space intended for a 375-psi boiler of the conventional type of twenty years ago. Its operating pressure (1850 psi) so reduced the head available for circulation that if the usual high-head type of unit had been adopted, it would have been necessary to remodel and reconstruct the building from its foundations. Other features, such as the ratio of water circulated to steam generated, control and proportioning of circulation in all parts of the unit, etc., outweighed any doubts introduced by reason of its novelty. The principle had been embodied in several hundred similar type units abroad. Difficulties were expected at the start of its operation and some were encountered. These were minor, however, when viewed in retrospect, and involved no radical changes in design.

This article is not intended to be a technical discussion of the elements of steam generator design. Its object is simply to enumerate some of the factors that must be considered when one is considering the installation of such equipment.

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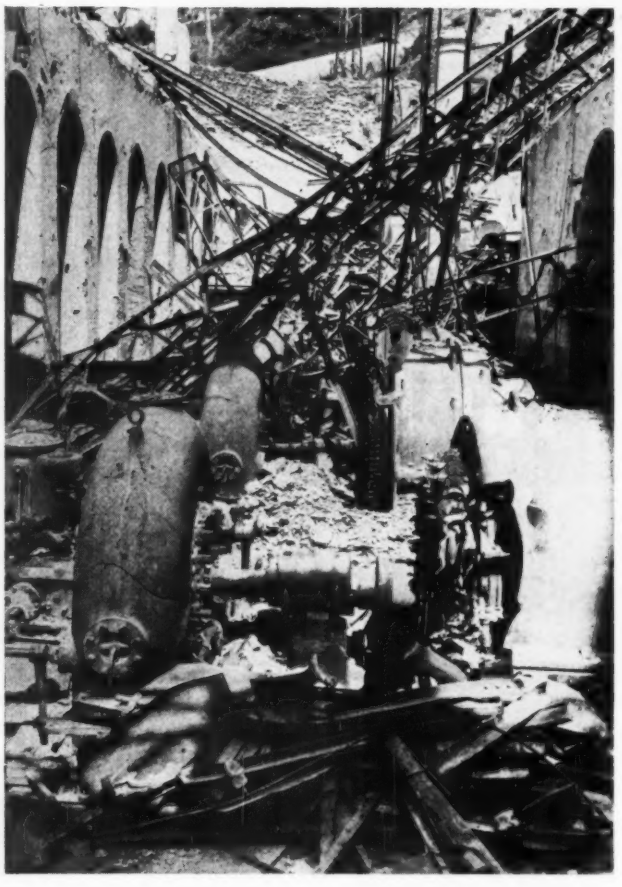


Views taken in the Papione Centralle generating station at Terni, Italy, which helped to supply Rome with electricity. The wreckage was caused by the retreating Germans.

(Official Army photographs)

WHAT ABOUT COPPER IN BOILERS?

By RICHARD C. COREY

Research and Development Dept.,

Combustion Engineering Company

In view of the common occurrence of copper deposits in high-pressure boilers and the diverse opinions as to its possible detrimental effects, the author reviews the chemistry involved, the various theories that have been advanced and the rather meager literature bearing on the subject. It is concluded that no valid evidence has yet been produced to show that metallic copper, or copper oxide deposits, will cause corrosion. Hope is expressed that the problem may form the subject of planned research involving both the laboratory and the field.

PROBABLY no other aspect of the broad subject of the deposition of solids on the steam generating surfaces of high-pressure boilers is as controversial today as the cause and the effect of metallic copper and copper oxides found so frequently in drums, headers and tubes. In answer to the questions of operators who are becoming concerned over such deposits, particularly when found in appreciable amounts at the site of tube failures, there is considerable conjecture, and little factual information. Much of this concern over copper appears to have been engendered by ill-advised, illogical theories. There appears to be no case on record, or in the author's experience, of a tube failure definitely attributable to deposits of copper or its oxides. Consequently, to claim at the present time that such deposits present a problem to the operator, from the standpoint of tube failures, has no basis in fact.

It is the purpose of the present article, by a brief review of what little is known about the subject, and a few fundamental facts, to stimulate further discussion.

General

The occurrence of large amounts of metallic copper and copper-oxides in the tubes, headers and drums of high-pressure boilers recently has been receiving more than casual attention. During the past few years, open discussion of the possible causes and the effects of copper has been heard, particularly at panel meetings of the A.S.M.E. Although the consensus of the majority appears to be that deposits of copper on generating surfaces are harmless, to date neither a valid mechanism for the formation of metallic copper nor positive evidence that such deposits cannot cause corrosion under operating conditions, has been offered. A number of theories, based upon speculation, and on rather dubious chemistry, have been proposed from time to time, but even casual consideration of these ideas leads to the conclusion that the whole subject is decidedly controversial and that the final answer lies in a laboratory investigation of the fundamental reactions of copper and certain of its compounds under the operating conditions of high-pressure boilers.

A review of the technical literature during the past 10 years disclosed only two articles (1, 2) in which copper was discussed in relation to corrosion in boilers. However, neither of these articles contained information based upon experimental facts. Thus, until there is available indisputable evidence of whether or not copper is potentially a corrosion hazard, the subject will remain debatable and little will have been done to allay the apprehensions of operators of high-pressure equipment. The fact that to date there has been no planned program of research on this subject undoubtedly is the result of wartime exigencies and not of apathy on the part of those directly concerned with the problem.

In the following will be presented some of the facts that are known about copper in boilers, the chemistry and the mechanism of corrosion of copper and its alloys, and a possible correlation of this information with the sequence of events during the passage of condensate from the hotwell back to the boiler.

Some Facts

1. Copper can only result from loss of metal from the tubes comprising surface condensers, closed feedwater heaters and evaporators during the passage of the water through them. Bronze pump impellers may contribute an insignificant amount of copper. The most common tube alloys used in condensers are aluminum-brass, aluminum-bronze or admiralty metal. Due to the higher temperature, flow and pH conditions in heaters, and evaporators, particularly those of high-pressure design, arsenical and silver-bearing copper or cupro-nickel tubes are generally used. The arsenic and silver are added to improve the hardness and the fatigue strength of copper. The cupro-nickel alloy (70 to 80 per cent Cu) has superior corrosion and erosion resistance to copper.

2. Ammonia and carbon dioxide (and bicarbonate) are known definitely to increase the solubility of copper in water; particularly in water of such high purity as steam condensate. Ammonia may come from the raw water supply or from condenser leakage. The latter is generally considered to be the source of most of the ammonia, particularly where contaminated tide water is used for condensing. The source of carbon dioxide is well known to everyone. It should be noted, however, that ammonia is far more effective than the same amount of carbon dioxide, as a solvent for copper. As much as is known of the chemistry of these reactions will be discussed later.

3. Deposits from boilers have been shown by X-ray diffraction analyses to contain metallic copper, cuprous oxide (cuprite), cupric oxide (tenorite) or mixtures of all three. Generally, the copper is associated with the usual boiler sludges and scales, comprising 1 to 50 per cent,

or more, of the material that is present. Frequently bright metallic copper is found plated on the tube surfaces, particularly where steam is being released.

It is common to remove large quantities of copper from a large unit after an inhibited acid-wash to remove scale. Apparently the acid loosens copper that is plated or deposited on the tubes and subsequent operations to remove all of the acid from the boiler cause the copper to settle in the headers where it is removed as extremely thin ribbons of metallic copper. There is some evidence that acid-washing, through solvent action of the acid on the copper oxides in the boiler, causes metallic copper to plate out on the steel surfaces. Theoretically, the conditions during acid-cleaning are suitable for this to occur, as will be discussed later.

4. There seems to be no preferred location in which copper is found; it occurs in drums, headers and circulating and generating tubes. Numerous cases have been reported of relatively large masses of loose, spongy, reddish-brown material analyzing very high in copper and copper oxide, occurring in feedwater headers. Due to the high feedwater temperatures coincident to high-pressure operation, it is probable that a greater pickup of copper from closed heaters and evaporators of such systems will occur than in low-pressure installations, other things being equal.

5. Not the least to be considered is the possibility that a considerable amount of copper pickup occurs in the heaters as a result of erosion or other mechanical effects.

Considering the enormous surface area presented to the flowing condensate by the condensers and other heat-exchange equipment it follows that any factor which increases only slightly the solubility of the metal will cause a material increase in the amount of copper carried to the boiler.

Mechanism of Corrosion of Copper and Chemistry of Certain Related Copper Compounds

In pure distilled water, free of oxygen, carbon dioxide and ammonia, the rate of corrosion of copper is negligible. The reaction between copper and water might be shown as follows:

$$2Cu(metal) + 2H_2O \longrightarrow Cu^{++} + 2OH^- + 2H \quad [1]$$

As no metal is perfectly homogeneous in the sense that every finite point on it is like another, such a surface may be considered to consist of innumerable small anodes and cathodes (3). At the anodes an almost infinitesimal amount of copper will go into solution as copper ions and an equivalent amount of hydrogen ions from the water will be reduced to atomic hydrogen at the cathodes. There are a number of factors which cause this reaction to come to equilibrium, as for example:

(*a*) The solution pressure of the metal becomes equal to the osmotic pressure of the copper ions.

(*b*) The surface becomes covered with hydrogen atoms which polarize the metal and prevent further solution of the metal.

If, however, some depolarizing agent such as oxygen is present to combine with the hydrogen as fast as it is formed, the reaction will proceed to the right to an extent far beyond that which occurs in its absence. In the same manner, any substance which will combine with and remove the copper ions as fast as they are formed also will stimulate corrosion of the metal.

We can now examine some of the substances which may be present in the feedwater cycle and which behave as described above.

1. Ammonia

Ammonia combines directly with copper to form a soluble, blue-colored, complex ion known as a copper ammine. In a general way, the reaction may be written as follows:

$$Cu(metal) + 4NH_3 \longrightarrow [Cu(NH_3)_4]^{++} \quad [2]$$

The chemistry of this type of compound is quite involved and no purpose would be served to dwell on it here. It should be emphasized however, that the copper in this complex is so tightly bound to the ammonia that the concentration of *free* copper ions in such a solution is insignificant.

A solution containing a small amount of copper ammine in a slight excess of ammonia, will precipitate all of its copper as a brownish-black oxide upon heating to around 150 F.

2. Carbon Dioxide and Bicarbonate Ion

Water containing dissolved carbon dioxide or bicarbonate ion markedly increases the solubility of copper in water. Although the chemistry is not fully understood, it is believed that copper forms a complex ion with bicarbonate ion similar to the ammine described above.

A paper by Tronstad and Veimo (4) gives the following data on the solubility of copper in tap water containing various additions of free CO_2 and bicarbonate ion after standing 24 hours at 18 C.

TABLE 1

$NaHCO_3$ Added, Ppm*	pH	Copper Dissolved, Ppm
0	6.3	0.6
0.1	7.0	1.0
0.2	7.1	1.2
0.3	7.15	1.8
0.4	7.2	1.9
0.8	...	2.2
1.2	...	4.5

TABLE 2

Free CO_2, Ppm*	pH	Copper Dissolved, Ppm
7.4	6.3	0.8
45.0	...	1.0
98.5	5.65	3.9
165.0	4.8	11.2
235.0	4.35	40.1

* The composition of water to which the additions were made was as follows: Total solids, 47.5 ppm; chlorides as Cl, 9.5 ppm; dissolved oxygen, 10.8 ppm; combined CO_2, 8.0 ppm; free CO_2, 4.0 ppm; pH, 6.3 ppm.

3. Dissolved Oxygen

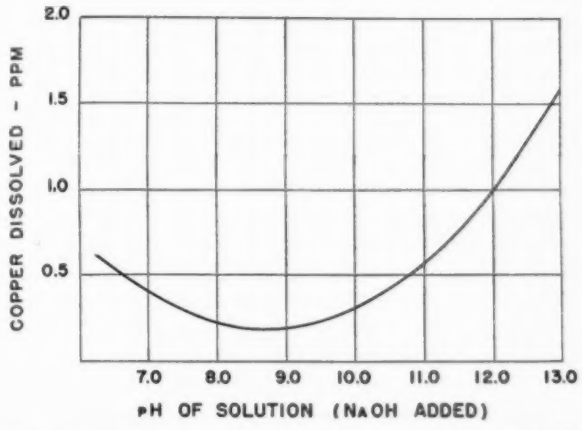
Dissolved oxygen increases the rate of corrosion of copper, particularly in the presence of acids. Apparently its action is to depolarize the hydrogen in equation [1] and to oxidize cuprous oxide, which may be present under certain conditions, to cupric oxide (or hydroxide).

4. Hydroxyl Ion

The effect of sodium hydroxide on the solubility of copper is shown in the accompanying curve. It is to be noted that a minimum in the solubility curve occurs around pH = 8.5.

The following are some of the reactions of copper ion with hydroxyl ion:

(*a*) Hydroxyl ion combines with cuprous ion to form reddish cuprous oxide, Cu_2O. With cupric ion,



The copper content of tap water of various pH values after standing 24 hr in copper pipes at 18 C. (Tronstad and Veimo).

a pale blue gelatinous precipitate of $Cu(OH)_2$ is formed. The latter product is the more common as there is usually sufficient oxygen, or other oxidizing agents, present to oxidize cuprous ion to cupric ion.

(*b*) Cupric hydroxide, $Cu(OH)_2$, will hydrolyze to a brownish-black hydrated oxide on heating the solution to around 150 F.

(*c*) Cuprous oxide, cupric oxide and cupric hydroxide all are appreciably soluble in an excess of hydroxyl ion (amphoteric) forming what is believed to be a complex oxyanion of the form $(CuO_2)^=$. This effect is analogous to the solubility of aluminum hydroxide in sodium or potassium hydroxide to form soluble aluminate ion. In the present case, the extent of solubility is very much less. Thus is afforded an explanation for the increase in the solubility of copper in sodium hydroxide above pH = 8.5.

The most urgent question to be answered regarding the effect of copper in boilers is whether or not the presence of metallic copper signifies the loss of an equivalent amount of boiler metal. It is well known that if iron is placed in a slightly acid solution containing free copper ions, the copper ions will be reduced to metallic copper (reduction implying that electrons have been added to the copper ions) and an equivalent amount of the iron will be oxidized to ferrous ions which pass into solution. These reactions may be written as follows:

$$Fe(metal) \longrightarrow Fe^{++} + 2e \qquad [3]$$

$$Cu^{++} + 2e \longrightarrow Cu(metal) \qquad [4]$$

(e = electron), the net reaction being

$$Fe + Cu^{++} \longrightarrow Fe^{++} + Cu \qquad [5]$$

The copper which plates out on the iron may vary in color from a dark, reddish-brown to a light coppery color, depending upon the pH and the temperature of the solution and the kinds of other ions that are present.

Thermodynamically, however, it can be shown that when the initial concentration of copper ions is below a certain value for a given set of conditions, reaction [5] will not take place as shown. For example, when the copper is combined in a complex manner, such as the copper ammine, or cuprite ions, or as an insoluble oxide or hydroxide, the tendency for iron to corrode and copper to plate on the iron becomes nil.

The corrosion of the boiler metal uniformly over the entire surface in contact with water, which potentially is able to exchange copper ions for iron ions, probably would not result in appreciable thinning of the steel over many years of operation. The serious consequence of corrosion by copper would be in the localized, pitting type of corrosion which might take place beneath small patches of deposited copper. Under such conditions, assuming the corrosion process to be electrochemical in nature, the total current of the small galvanic cell formed between the steel and the copper would be distributed over a small area and the current density would become extremely high resulting in rapid penetration of the metal. The mechanism of this type of corrosion is more fully described in a recent article (3).

Results of Simple Test

The following simple experiments with copper, although by no means comparable with tests made under operating conditions, suggest that the manner in which metallic copper is plated out on steam generating surfaces is by no means amenable to a simple explanation.

Place a piece of clean copper in 100 ml of distilled water containing 1 ml of ammonium hydroxide. In 24 hr the solution assumes a clear, deep-blue color signifying the presence of the copper ammine ion. This solution then is divided into two equal parts. Into one part a piece of clean boiler steel is placed and allowed to stand for 48 hr at room temperature. *No metallic copper will plate on the steel in this time.* The other half of the solution is slowly heated and at about 150 F a brownish turbidity develops which changes later to a brownish-black precipitate, which presumably is hydrated cupric oxide. The blue color disappears, signifying that all of the copper now is present as the insoluble oxide. A piece of clean boiler steel is placed in this solution and allowed to stand for 48 hr at room temperature. *No copper will plate on the steel.* To this solution, containing the steel specimen then is added sufficient sodium hydroxide to make the concentration 500 ppm and the ammonia driven off by boiling for a few minutes. After standing for 48 hr at room temperature, *no copper will be found to be plated on the iron.* These tests show that when the copper is combined in a complex ion, such as $(CuO_2)^=$ or $[Cu(NH_3)_4]^{++}$, it will not plate on iron and that the cupri-ammine ion hydrolyzes to an insoluble oxide upon heating to about 150 F. The first half of the original blue solution, containing the iron specimen, then is made acid to about pH = 5.0 with hydrochloric acid. Within 4 or 5 hr all of the copper will plate out on the iron as a reddish-brown loose deposit. This last experiment simply demonstrates the validity of equation [5].

Discussion of Theories

Before attempting to correlate the above factors with operating conditions, it is desirable to discuss very briefly some of the theories that have been proposed by exponents of the idea that copper in boilers is harmful.

It has been stated by some that copper acts as a catalyst in the decomposition of steam to hydrogen and oxygen, the resulting hydrogen diffusing through the steel to cause embrittlement and the oxygen combining

with the steel to form iron oxide, thus increasing the rate of corrosion of the steel. This is specious reasoning which fails to meet the premise that copper is harmful, inasmuch as it is fundamentally incorrect. A catalyst will not change, at any stated conditions of temperature and pressure, the equilibrium ratio of hydrogen and oxygen to water vapor, as is implied above. The sole purpose of a catalyst is to increase the *rate* of a reaction toward a given state of equilibrium. Furthermore, if it is assumed, for the sake of argument, that copper will increase the amount of hydrogen and oxygen in equilibrium with the steam, there is no reason to believe that the oxygen preferentially would oxidize the steel.

Another statement that has been made is that metallic copper deposited on the surface of the steel will, at operating temperatures, diffuse into the steel and induce brittleness. Calculations from the diffusion constant for the rate of diffusion of copper into steel, in the temperature range of boiler operation, shows that it would require many years of contact, under ideal conditions, of the two metals to effect penetration of the order of 0.001 in. It is true that copper in steel makes it hot-short, that is, difficult to forge without cracking, but there is no evidence that a small amount of copper in solid solution in steel would impair its physical properties at the usual operating temperatures.

To account for the presence of metallic copper in boilers it has been suggested that the hydrogen generated by reaction of the steam with the hot steel surfaces reduces the copper oxides to metallic copper. Hydrogen normally occurs in all boilers to a certain extent. Under conditions where overheating occurs, so that steam is in contact with iron above about 1000 F, the amount of hydrogen is increased. If, however, one calculates the partial pressure of hydrogen in a boiler under normal conditions, it will be found to be of extremely low magnitude. For example, recently the partial pressure of hydrogen in a 1400-psi, 900-F boiler was calculated to be of the order of 1.5 microns Hg, based upon the amount of hydrogen collected from a 24-hr sample taken at the superheater outlet. The amount of hydrogen dissolved in the boiler water at this partial pressure is insignificant and could not conceivably have sufficient reduction potential to effect reduction of the copper oxides to metallic copper, particularly in the usual pH range of boiler water.

On the other hand, if a hot-spot develops on a steaming surface, so that a relatively high concentration of hydrogen is generated locally, the reduction of copper oxide deposits at the site of attack might take place. This, however, does not account for deposits of metallic copper in drums and headers, where no steam is being generated.

Considering all of the above factors collectively, it is of interest to consider the sequence of events in a condensing cycle using low, evaporated makeup, and see if any correlation exists. The obvious defect of such a procedure is that observations made under conditions where temperature, pressure, velocity and other environmental factors are not the same as those of actual operating conditions, may not be applicable. Nevertheless, certain qualitative conclusions may become apparent which will serve as a basis for experimental procedures.

After leaving the condenser the condensate, which will be at about 90 F, and have a pH between 5.0 and 7.0, may contain a small amount of ammonia derived from condenser leakage, carbon dioxide from the steam, possibly some dissolved oxygen, and copper combined as a complex compound of ammonia or carbon dioxide, the copper being derived from the brass condenser tubing. As the condensate passes through closed heaters, an increase in the amount of dissolved copper may be expected. Simultaneously, however, the increase in temperature of the condensate will tend to hydrolyze the copper complex to an insoluble oxide so that by the time the water enters the boiler the copper all will have been precipitated from solution. In the usual pH range of the boiler water, 10–11.5, and a temperature of between 450 and 600 F, some of the oxide may be converted to the complex $(CuO_2)^=$ form.

The reactions of the copper thereafter remain an open question, to be answered in the laboratory.

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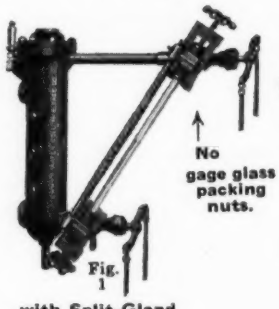

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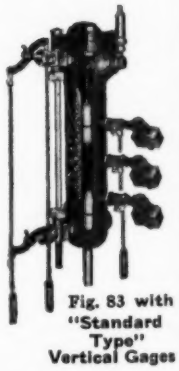

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THE GAS TURBINE IN AVIATION

By C. D. FLAGLE and F. W. GODSEY, JR.

Westinghouse Electric Corporation

A comparison of the performance, limitations and most favorable spheres of application for the reciprocating internal-combustion engine, jet propulsion and gas turbine propeller drive for airplanes, with particular reference to take-off, speed, altitude, fuel consumption and operating range.

UNTIL recently, airplanes were driven only by reciprocating internal-combustion engines. Now there are new power plants and of them, two will undoubtedly figure largely in aviation of the near future. One is the jet-propulsion engine and the other the gas turbine-propeller drive. Both will have continuous combustion gas turbines as the prime mover.

While the reciprocating engine will undoubtedly continue to hold its present position in the field of low power and for planes of relatively low speed, the gas turbine will come into its own both as a jet engine and for driving propellers in high-powered planes and for high-speed flight.

Of the three types of power plants, the gas turbine-propeller engine has characteristics that give it superiority over the reciprocating engine in all speed ranges and over the jet engine in low and intermediate speeds. The jet is pre-eminent in the highest speed range. Fig. 1 shows the probable fields of use of the three types.

The Reciprocating Engine

Development of the modern reciprocating aircraft engine is one of the great technical achievements of our age, inspired to no small degree by military requirements. That the primary objectives of efficiency, light weight and reliability have been met need hardly be repeated here. However, power ratings have reached a point where further major increases can probably only be attained by improvements in fuels or the addition of cylinders. The diameter or frontal area of engines is already limited by allowable piston speeds, larger engines are longer engines, and the specific weight is more apt to increase with power rating than decrease. Unfortunately, reciprocating engines capable of delivering several thousand horsepower require controls, accessories and exhaust disposal systems which complicate installation and maintenance problems to an extent that limits further large increases in power rating.

The reciprocating engine is by nature adapted to cruising flight rather than sustained high-speed flight. Its highest efficiency and greatest reliability are achieved only when the engine is operated below 60 per cent of rated power. An underpowered airplane is constantly plagued by power plant troubles of a mechanical nature. Fig. 2 shows some typical fuel rates at various operating conditions.

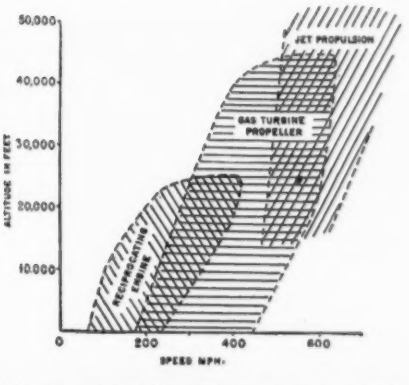


Fig. 1—Probable fields of use of the three types of aircraft power plants

Gas Turbine-Jet Engine

Jet propulsion of aircraft has recently become a subject of much publicity and confusion. In jet propulsion, all the power output of the engine is used to accelerate the air taken into the engine to a jet of approximately acoustic velocity which is expelled through an exhaust nozzle. The resultant thrust felt by the engine housing is the reaction to the force required to accelerate the intake air to its exhaust velocity. (Rockets also work by accelerating their internal charge to a high velocity, but they carry their own oxygen and fuel, making them independent of the atmosphere.) The gas turbine operates by inducting air, compressing it, adding heat at high pressure, and expanding the high-temperature combustion products. The major part of the energy is recovered in expansion through the turbine blading and must be used to supply energy required for compression. The remainder of the expansion can be made to take place through a nozzle, where the energy appears as kinetic energy of the exhaust gases.

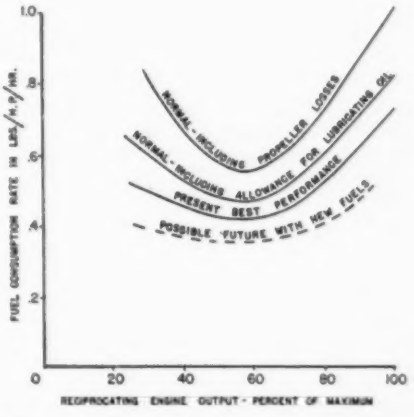


Fig. 2—Typical fuel consumption rates for a large reciprocating aircraft engine under different operating conditions

One may ask why the gas turbine can be so well adapted to jet propulsion while the conventional engine cannot. The answer lies to a great extent in the fact that the gas turbine handles a much greater mass of air (four to eight times greater than the reciprocating engine for each pound of fuel burned) which leads to a more efficient jet reaction. The difference here is that the reciprocating engine requires a large mass flow of air for cooling external to the combustion space, while the gas turbine swallows its own cooling air and subjects it to the same thermodynamic cycle as the air needed just to burn the fuel. The relatively high combustion temperatures of the reciprocating engine result in high-speed exhaust gases with very unfavorable velocity ratios for jet flight at subsonic speeds.

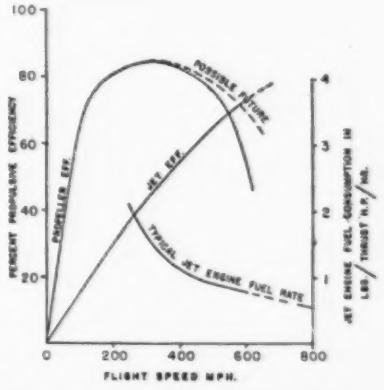


Fig. 3—Propulsive efficiencies of propellers and jets of jet engines. The fuel consumption of a typical Jet Engine is also shown

The principal advantages of the jet engine are its simplicity and light weight. The installed weight of the jet propulsion engine is little higher than its dry weight, since little oil is required for lubrication, and the engine itself requires no external cooling provisions.

The jet engine's thrust is relatively constant over normal airplane speed ranges. Therefore, the rating of a jet engine is usually given in terms of thrust rather than horsepower and means nothing from a power standpoint until the speed is also given. A thrust of 1 lb at a speed of 375 mph is equivalent to one horsepower;

at lower speeds the power rating decreases and at higher speeds it increases in direct proportion.

An adjustable-pitch propeller is capable of converting shaft power into thrust horsepower rather efficiently over a wide range of airplane speeds, but the jet's efficiency is quite low at low speeds. This is shown in Fig. 3, in which it can be seen that present jet efficiency does not equal

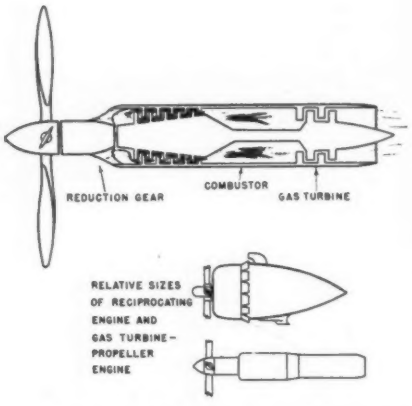


Fig. 4—Schematic illustration of axial flow gas turbine-propeller engine

propeller efficiency until flight speeds of about 500 mph are attained. Below this speed the jet efficiency, consequently its fuel economy, is inferior. The fuel efficiency of a jet engine is low, principally because of the jet efficiency characteristic; secondly, because the gas turbine itself operating at a low compression ratio is handicapped in efficiency.

It is significant that jet efficiency overtakes propeller efficiency in a speed range in which compressibility effects impose critical aircraft design limitations. Much aerodynamic research must be carried out before jet propulsion can be utilized to its best advantage.

Gas Turbine Propeller Drive

A simple open cycle gas turbine can be built today to work at a peak temperature (temperature of gases entering the turbine) of 1500 F. With further metallurgical progress, the life of highly stressed turbine parts operating under high temperature will be increased and the limiting cycle temperature may be elevated above 1500 F. With a compression ratio of 10:1 and compressor and turbine efficiencies of 85 per cent, a fuel efficiency of 26 per cent can be achieved. By increasing compressor efficiency to 87 per cent and turbine efficiency to 89 per cent we may expect a rise in efficiency to 28 per cent at standard sea-level conditions. At 15,000 ft, due to low ambient temperatures, the cycle efficiency rises to 31.5 per cent.

A schematic illustration of a gas turbine geared to a propeller is shown in Fig. 4. In appearance, the axial flow gas turbine for propeller drive will be a symmetrical machine, its reduction gear concentric with its rotor. Its diameter will be less than half that of a conventional reciprocating engine of comparable power, permitting it to be easily buried within a fuselage or wing. Presenting little frontal area and requiring no external cooling air for itself, the gas turbine offers very little drag at high speeds. This, in addition to the fact that the gas turbine efficiency is best at its peak load, points to the adaptability of this type of power plant to high-speed flight.

The efficiency of a gas turbine is highest at its rated load and rated rpm. As the rpm decreases, the efficiencies of compression and expansion drop off and the compression ratio also decreases rapidly. Since the useful power output of the machine is the relatively small difference between the power developed by the turbine and power absorbed by the compressor, any change in compressor or turbine efficiency is magnified in its effect on power output. In fact, it is doubtful if the turbine output will be sufficient to drive the compressor—much less supply power to the propeller at much below one-half rated speed.

The gas turbine for propeller drive operates on four to eight times the quantity of air used by a reciprocating engine of com-

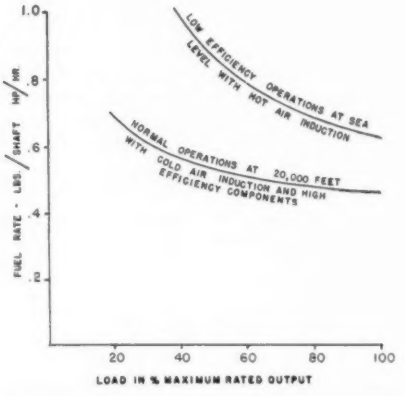


Fig. 5—Range of fuel consumption rates for aircraft gas turbines with reduction gear output to propeller shaft; rates have not been adjusted for exhaust jet thrust effects

parable power. A large exhaust jet thrust is available to supplement the propeller, since normally about 20 per cent of the useful power remains in the exhaust gases as kinetic energy; the proportion of useful power remaining in the exhaust to power delivered to the propeller can be controlled by the designer.

The gas turbine will permit a much lighter power plant installation than will the reciprocating engine. The installed weight of the geared gas turbine plant should be less than three-fourths the weight of the equivalent reciprocating engine installation.

In general, operations at normal flight altitudes are favorable to economical turbine performance; fuel rates are indicated in Fig. 5. It is interesting to note that for rough approximation purposes, the exhaust jet thrust just about compensates for propeller losses and nacelle and cooling drag, so that the shaft power output of the turbine is just about equal to the net thrust horsepower available. This is very different from the reciprocating engine.

The gas turbine is not a supercharged engine. Therefore, the selection of power rating must be based on altitude requirements; and for sea level operation, considerable excess power will usually be available. Typical power availability curves for various types of power plants are shown in Fig. 6.

The foregoing describes the principal features and characteristics of conventional reciprocating engines, gas turbines geared to propellers, and jet engines. How they are now used and how they can best be applied will next be considered.

The reciprocating engine, in its normal cruising power range, is a very efficient means of converting fuel energy into shaft power. However, its application to aircraft is complicated by many difficult problems, among which are the necessity for supercharging at high altitudes, severe vibration, excessive weight installed as compared with dry engine weight, and high nacelle drag and engine cooling power losses.

For medium range and long range aircraft, the most important problems are probably the reduction of nacelle drag and engine cooling losses. Airplanes designed for low-speed operations can afford to have a large part of the plane's parasitic drag absorbed in engine nacelle and engine cooling losses, since induced drag may be a large portion of the total flight power requirement and engine losses are a relatively minor factor. This is distinctly not the case with long-range and high-speed aircraft where induced drag is relatively small and parasitic drag all-important.

The reciprocating engine presents a large frontal area when placed in a wing nacelle, and the total profile area of power plant frequently exceeds that of the fuse-

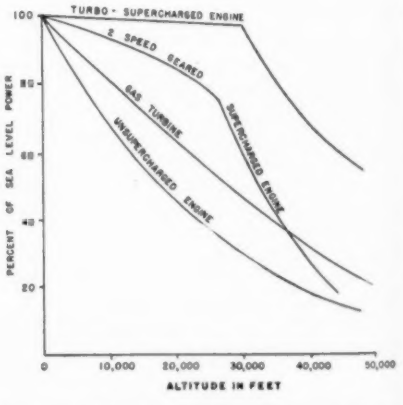


Fig. 6—Effect of altitude operations on power availability of various typical aircraft engines

lage. Similarly, the reciprocating engine requires large volumes of cooling air that must be forced around the cylinders of air-cooled engines or through the radiators of liquid-cooled engines as well as through numerous accessories and oil coolers. Fig. 7 shows the power losses at different airplane speeds for a typical 2000-hp engine installation complete with propeller and installed in a wing nacelle. The remaining available power under any but low-speed flight conditions is greatly reduced by these losses.

The axial-flow jet engine is capable of delivering almost constant thrust at all speeds from take-off to dive maximum. Throughout this speed range, fuel is burned at practically a constant pounds per hour rate, and changes in speed have but little effect on thrust or fuel consumption. Further, the jet propulsive efficiency is approximately proportional to speed, as shown in Fig. 3. These factors will lead to the use of jet engines in high-speed aircraft. At low air speeds, fuel consumption rates are exorbitant when compared with propeller-driven aircraft.

To offset the disadvantage of low efficiency at low speeds, the jet engine delivers a lot of power for very low installed power plant weight in its proper flight speed range. Cycle efficiency, while not good, is fair, which means low fuel cost per thrust horsepower at very high speeds, and the engine's diameter is small enough to permit buried installations in the wings of any but the smallest planes.

Apart from booster applications in aircraft that are underpowered with reciprocating engines, jet engines should not be installed in any but the cleanest of low drag airplanes. The most suitable applications for jet propulsion appear to lie in speed ranges where compressibility effects are the principal unknowns; supersonic problems are fairly well known from ballistics and low-speed flight has been well explored, leaving the natural flight speed range of the jet engine a large blank.

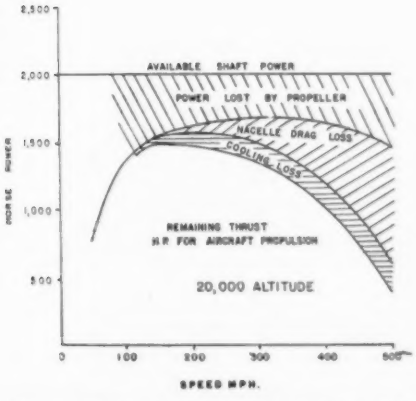


Fig. 7—Typical losses associated with a large reciprocating engine in a wing nacelle and operated at full power

The gas turbine geared to a propeller has the advantages of the jet engine with respect to drag reduction and ease of installation, while at the same time retaining the high propulsive efficiency of the propeller at low speeds. The present limit of usefulness of the geared propeller turbine at high flight speeds is set by the characteristics of available propellers which lose out quite rapidly in efficiency above 500 mph.

It is possible to make a choice of the division of power outputs of a turbine propeller unit between jet exhaust thrust and the propeller shaft. For example, for a very high-speed airplane that must still have a good take-off characteristic, 50 per cent of the power might be used in jet thrust and the remainder in the propeller. For ordinary applications, however, between 20 per cent and 25 per cent of the available energy should remain in the exhaust jet, the turbine shaft recovering the remainder.

The field of usefulness of the gas turbine with propeller extends to all aircraft requiring engines of greater than perhaps 1000 to 2000 hp, and designed for all speeds up to and in excess of 500 mph.

The conventional engine installation is four engines supercharged to 2000 horsepower each at 20,000 ft. In the jet-propelled version, four 6000-lb static thrust engines are used; this will give 24,000 lb take-off thrust, approximately equal to the take-off thrust of the plane with reciprocating engines. Once in flight, two of the jet engines would be shut off for cruising under 25,000 ft altitude and the other two would be used for propulsion. In the gas turbine geared propeller version, four engines capable of delivering 2000 shaft horsepower each at 20,000 ft would be used. At take-off these engines will deliver 3200 hp each. A propeller designed to absorb 2000 hp in the low density air of 20,000 ft altitude can handle 3800 hp at sea level with the same level of propulsive efficiency.

CRUISE CONDITIONS (20,000 FT ALT.)

	Best Cruising Speed, Mph	Miles per Lb Fuel	Extreme Range, Miles
Conventional	250	0.120	4800
Turbine Propeller (4 engines)	300	0.125	5700
Turbine Propeller (2 engines)	280	0.145	6600
Jet Propelled (2 engines)	350	0.050	2650
Jet Propelled (4 engines 35,000 ft alt.)	460	0.066	3500

The sensitivity of the gas turbine propeller to partial load operation is seen in the table. An 18 per cent increase in range is obtained by operating two engines close to full load and maximum efficiency rather than operating four engines at less than half load. This is a fundamental difference that exists between turbines and reciprocating engines, and it makes necessary a careful selection of turbine ratings for any given application if maximum fuel economy is to be gained. The same conditions are true of jet propulsion engines, and it is profitable to operate close to 80 per cent of full rating of the turbines either by shutting down excess power units or going to a sufficiently high altitude to decrease the maximum rated output to a value near the required flight power. In the case of jet propulsion, since high speed and high propulsive efficiency go together, very high altitude operation is essential to maximum flight economy.

The general characteristics of the three types are compared by the bar charts of Fig. 8. It is interesting to note that the gas-turbine propeller airplane is superior to the conventional aircraft on every count with the exception of altitude ceiling, where they are about equal if the reciprocating engines are turbo-supercharged. Since turbine propeller fuel economy and installed power plant weights are both superior to those of the conventional engine, the long range and short range load carrying abilities of the turbine propeller aircraft are superior to the conventional one. On the other hand, the jet propelled aircraft has a very light power plant installation and can get off the ground for very short flights with about five tons more payload than the conventional aircraft, and about three tons more than the turbine propeller version. However, jet propulsion requires so much more fuel than other types of power plant, that at about 2000 miles extreme range the jet plane loses out to the reciprocating engine and is far behind the geared turbine in payload carrying ability.

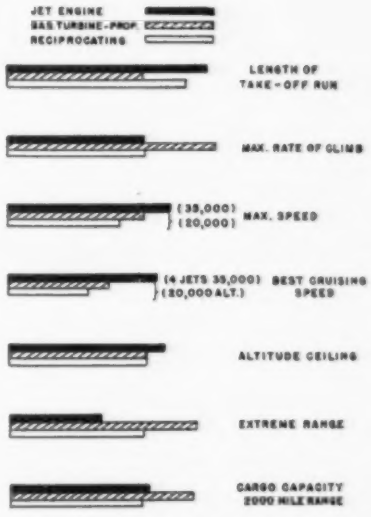


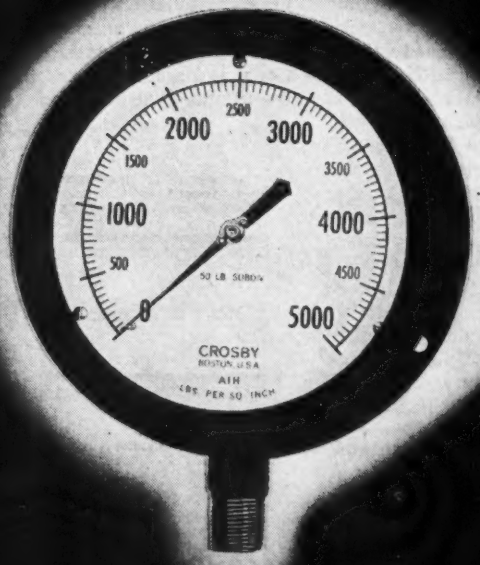
Fig. 8.—Comparison of the characteristics of the three types of propulsion

Oil Requirements

Speaking recently before a Pacific Coast meeting of the American Petroleum Institute, Ralph K. Davies, Deputy Petroleum Administrator for War, gave the following figures on current oil requirements:

The world-wide requirement of the United Nations exceeds 7 million barrels of oil per day. Of this the United States is called upon for 5,150,000 bbl, or 69 per cent; South America 14 per cent; countries of the Middle East 7 per cent; and Russia 9 per cent. In the United States the current rate of production exceeds even the maximum efficient rate for the fields by some 200,000 bbl per day—a condition justified only by the national emergency.

California operating on an unprecedented scale of close to a million barrels per day, supplies only 42 per cent of the total requirement of the Pacific theater; 28 per cent of these requirements is coming from the Caribbean; 14 per cent from inland United States and the Gulf; 2 per cent from Peru; and 14 per cent from the Persian Gulf. Movement of crude oil and its products from Texas and the mid-continent fields to California is now 140,000 bbl per day.



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Unit Power Plants for Export

Speaking before the Metropolitan Section, A.S.M.E. on May 22 Charles A. Muessel, of Westinghouse Electric International Company, told of the development by his company in conjunction with Burns & Roe, consulting engineers, of unit power plants for export.

The plan was conceived in 1939 and after preliminary designs had been worked up for a 1000-kw condensing plant for operation at 425 psi 740 F, proposals were submitted early in 1941 to representatives of the Chinese Government.

Chinese Plants

The plants destined for China presented many unusual design elements. They were intended to be installed in natural or artificial caves, the design contemplating two parallel caves—one for the boiler room, and the other for the turbine room, with a rock wall between. The roof of the caves was to be excavated to form a barrel vault about 30 ft high for the turbine room and 60 ft high for the boiler room. Long access tunnels provided means of reaching the two operating rooms as well as serving as ventilation intakes. This construction was selected as a protection against aerial bombs, and combustion gases were to be delivered by induced-draft fans to camouflaged offset shafts whose outlets were a considerable distance from the boiler room.

The first of these Chinese plants was intended for the upper reaches of the Yangtze River which has a yearly variation in water level of some 65 ft and a maximum stage level difference of 75 ft. Therefore, the boiler- and turbine-room floor level had to be set at 11½ ft above the highest recorded flood-water stage. This extreme fluctuation in river level presented a problem in obtaining circulating water for condenser cooling, which was solved by the use of deep-well pumps.

Geared turbine-generator sets were selected primarily because they could be broken down into packages of permissible size and weight for truck transport over the Burma Road, but this arrangement which has been adhered to for later units also affords flexibility in speed and frequency.

Because of the temporary closure of the Burma Road the original eleven units destined for China had to be placed in storage on the Pacific Coast, but some of these have since been shipped and are now being erected.

Next, 2000-kw unit plants were designed with the turbines and boilers similar in general design to the 1000-kw units. Seven of these were intended for China, but have since been diverted to Russia and Italy, and to the Netherlands for pumping inundated areas.

Plants for Russia

Subsequent Russian orders contemplated plants of both 1000- and 2000-kw capacity to be housed in brick and concrete structures. As some of these were to be erected in northern Siberia, where temperatures range from plus 85 F to minus 62 F, unusual design and operating problems were involved. For these installations the condenser cooling water system employs standard spray-pond construction for use at outdoor temperatures above 32 F, but has available a separate circulating system which circulates the cooling water under the ice cap in the spray pond during extreme cold weather. In addition, an anti-freeze circulating system is located at the makeup water pump house.

A variety of fuel conditions had to be met. The Chinese plants contemplate the use of coal only, of about 10,100 Btu per lb and 30 per cent ash, whereas the coal for the Russian plants runs as low as 6680 Btu per lb and 26 per cent ash. The Russian fuel situation was further complicated by the desire to burn peat and wood, either alone or simultaneously with the coal.

The wood-firing system includes a motor-driven hogger to chip meter lengths of cordwood, six inches or less in diameter, to a fineness of approximately puffed wheat or rice. A separate wood stoker controls the flow of hogged fuel to the feeder nozzles located in the front wall of the boiler.

The boilers for the above-mentioned units are of the bent-tube, S-A type with a 42-in. steam drum and two 18-in. lower drums, each served by a spreader stoker firing over a traveling grate. The turbine-generators are of 12-stage impulse design operating with steam at 400 psi 725 F at the throttle and a 28-in. vacuum. Steam is bled for feed heating and evaporating the makeup. A double helical reduction gear and pinion connects the turbine and generator and the speed reduction is 4425 to 1000 rpm. All piping is prefabricated in sizes above 2 in.

In these developments standardization was a prime objective, thereby reducing initial cost and materially simplifying both erection and maintenance. Each size of power plant consists, basically, of a boiler, turbine, feedwater heaters, necessary auxiliaries, switchgear and a circulating water system.

Export Conditions

Commenting on post-war export possibilities for such standardized unit power plants, Mr. Muessel stated that the average foreign purchaser of plants from 500 to 5000 kw capacity is receptive to a completely fabricated plant, not requiring the services of a consulting engineer, in contrast with practice in this country. Moreover, the foreign purchaser has not learned to expect excess capacity over that for which he contracts. It is important that all dimensions and drawings be in the metric system and that gages be marked in atmospheres rather than pounds pressure. Moreover, because of low fuel and labor costs in many countries, efficiency is of secondary importance and only simple controls are warranted. He did not anticipate much of a market for such plants in the United States.

Losses in Coal Production

The 19-day strike of the anthracite miners in May resulted in lost production of 3½ million tons, as estimated by the Solid Fuels Administration. This would have supplied the heating requirements of some 400,000 homes next winter.

During the calendar year 1945 to May 19, on which date the strike was terminated, the output of anthracite totaled only 19,341,000 tons which was 6,253,000 tons less than that during the corresponding period last year. Thus over one-half the deficit was due to the strike and the remainder is attributed to manpower shortage at the mines.

Production of bituminous coal for the present year up to May 19 was 227,155,000 tons which was a decrease of 20,273,000 tons over the comparable period for 1944. While part of this deficiency was due to manpower shortage and to transportation difficulties during the severe winter weather, a considerable portion has also been due to sporadic strikes in various mining districts, some of which occurred or continued after the new wage contracts went into force.

In view of this situation, the Solid Fuels Administration is urging all consumers to purchase and stock up during the summer months, so as to keep the demand up and help alleviate conditions during the fall and winter months.

While substantial cut-backs and plant reconversions may ease the fuel problem temporarily in some areas, it is likely that most of the plants not engaged in war production for the Pacific will resume capacity as soon as possible to fill deferred civilian needs. Moreover, with termination of the "brown-out" and "curfew" the fuel saving which they represented must be saved elsewhere. Hence, the National Fuel Efficiency Council has been requested by the Bureau of Mines to redouble its efforts for the remainder of the year toward achieving maximum fuel conservation among industrial and commercial consumers.

Army Engineers' Floating Power Plants

Increased demands for power, due to the war, resulted in overtaxing existing utility systems in certain areas throughout the country and necessitated the construction of several mobile power units capable of being readily moved from one location to another temporarily to relieve critical power situations in specific areas until such time as permanent relief could be provided for those areas. These floating power plants were developed by the U. S. Army Engineers Corps, one of the largest of which is called the "Inductance" and rated at 30,000 kw is operated by the Memphis, Tenn., Army Engineer district.

The plant is housed in a steel hull 318 ft long 50 ft wide and has a maximum draft of 14 ft. Since it is a floating plant, it can be moved to any point accessible to water transportation. Power is generated at 13,800 volts by a 30,000-kw alternator driven by a 19-stage steam turbine. Steam is supplied to the turbine at 850 psi and a temperature of 900 F by two

marine express-type boilers equipped to burn either oil or gas separately or simultaneously. Two 300-kw diesel-driven generators are provided for emergency use aboard the plant and for starting-up purposes. A three-phase power transformer rated at 37,500 kva is provided to raise the generated voltage to a value suitable for transmission. Taps are provided so that voltages ranging from 63,100 to 138,000 may be obtained as required. Although rated at 30,000 kw, the plant can deliver 36,000 kw for an extended period. A total of 43 persons are required to keep the plant in operation 24 hr per day.

In addition to the power generating equipment described, there is included as a part of the plant, a shop with the necessary machine tools and equipment for making general operating repairs, a gallery and living quarters for feeding and housing the operating personnel, and an office for handling administrative work in connection with operation of the plant. The unit therefore is capable of operation, if necessary, in isolated localities for extended periods of time.

Areas Served

The plant has been in operation approximately seventeen months. During this period it has generated electrical energy for distribution over the power lines of the Mississippi Power and Light Company for serving the area around Vicksburg and Jackson, Mississippi, and the Gulf Power Company for serving the area around Pensacola, Florida. Approximately 264,724,000 kwhr of electrical energy have been generated to date.

At present the "Inductance" is stationed at Jacksonville, Florida, furnishing power to supplement the power generated by the city's municipal generating plant. Due to the tremendous load demands on the city power plant, it has not been possible to shut down any of the units of the plant for needed repairs. With the "Inductance" supplying power into the municipal power system, the city now can shut down some of these power units and make the necessary repairs thereto without sacrificing services to the city as a whole.

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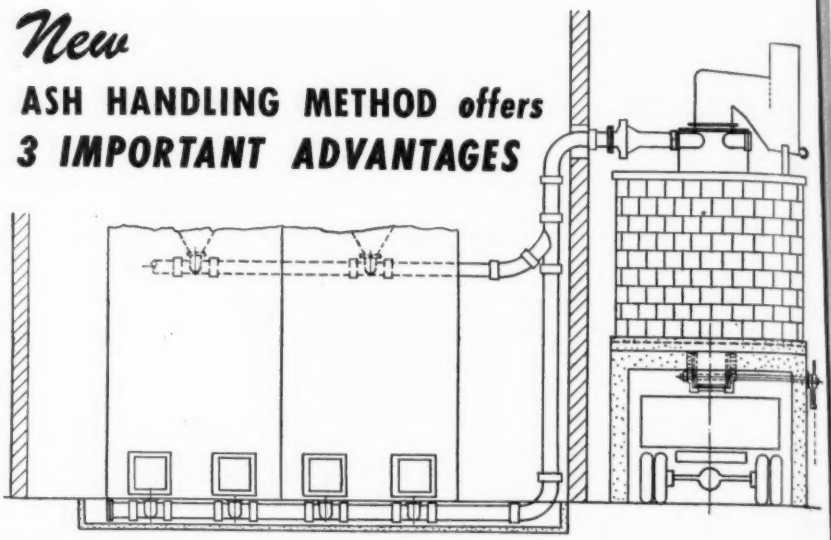

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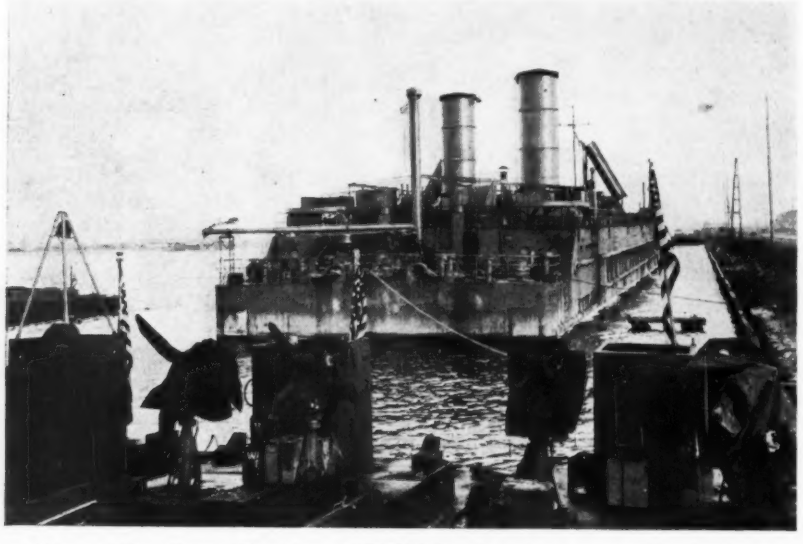
Present plans call for continuous operation of the plant for the duration of the war. Another of these units of 25,000 kw capacity was sent abroad and is serving as an auxiliary power plant for emergency use in a European harbor. This is shown in the accompanying photograph recently released by the Bureau of Public Relations of the War Department.



One of the Army Engineers' 25,000-kw floating power plants in a European harbor

Personals

Elmer L. Lindseth, formerly production engineer and later executive vice-president of the Cleveland Electric Illuminating Company, has been elected president of that company, succeeding the late Eben G. Crawford.

J. S. Wise, after nearly half a century spent in the electric industry, has retired as president of the Pennsylvania Power & Light Company.

Philip Sporn, for some years vice-president and chief engineer of the American Gas & Electric Company, has been advanced to the position of executive vice-president.

J. I. Yellott has resigned as Director of Mechanical Engineering at Illinois Institute of Technology to become Director of Research for the Locomotive Development Committee of Bituminous Coal Research. He took up his new duties on May 1 with headquarters in Baltimore.

W. G. Davenport has been elected president of the Beaumont Birch Company, manufacturers of coal-, ash- and materials-handling equipment.

Prof. G. L. Tuve, of Case School of Applied Science, has been appointed head of the Department of Mechanical Engineering, as of July 1, to succeed Prof. F. H. Vose, who has held that post for 31 years.

A. E. Candle has been appointed sales manager of the blower and compressor department of Allis Chalmers Company.

Boiler Inspectors Meet

THE Fifteenth Meeting of the National Board of Boiler and Pressure Vessel Inspectors was held at the Hotel McAlpin, New York, May 22–24. Because of ODT restrictions out-of-town attendance was limited to about thirty-five members representing states and cities having boiler inspection departments, but local attendance included representatives of insurance companies and manufacturers, as guests. The program was devoted entirely to business sessions.

Following brief addresses by **Gerald Gearon,** Chairman of the National Board, **A. C. Weigel,** President of the American Boiler Manufacturers Association and Affiliated Industries, and by **H. B. Oatley,** Chairman of the A.S.M.E. Boiler Code Committee, a number of pertinent topics were discussed. These included the following:

"Explanation of a Peculiar Tube Failure" was given by **Charles Sattler** who told of a 4-in. tube in an hrt boiler which had a shim under the tube seat to insure tightness. Because of the high-ash coal burned it was the practice to steam lance the tubes at intervals, but considerable water had been allowed to accumulate in the hose and was not blown out. When the lance was next applied the cold water contracted the tube and it pulled out. The peculiar aspect of the failure was that the tube was projected longitudinally, like a rocket, and did considerable damage besides scalding the operator.

A. L. Colby showed slides of a number of failures of oil-fired boilers in the State of Louisiana, which accidents were attributable to low water and incompetent operators. Fifteen such cases had occurred within the last three years in that state alone, resulting in nine fatalities. Discussion revealed that accidents due to low water have been general during the last 18 months in many sections of the country, particularly with small boilers in which too much dependence was placed on automatic control without efforts being made to assure that these controls were maintained in proper working order.

Considerable discussion centered around a proposal that the A.S.M.E. Boiler Code Committee consult the National Board before making drastic changes in Code Rules and the possibility of Code revisions and changes being accepted by the National Board on January 1 of each year only. This, it was contended, would enable inspectors to keep better informed, for at present many shop inspectors are confused by interpretations issued from time to time.

On behalf of the Boiler Code Committee it was pointed out that special requests are frequently received, both from enforcement groups and manufacturers for rulings concerning new construction, not already covered, which must be tried out before putting into the Code. Many of these concern welding and advances in metallurgy. These result in issuing interpretations throughout the year, but the pink sheets designating changes in the Code are issued only once a year, usually in September or October. The Boiler Code Committee, while conscious of the problem, still would not be justified in holding up construction in some cases for many months before issuing an interpretation. In fact, a large number of these deal with transient matters and do not form the basis of printed interpretations. In some states changes in the A.S.M.E. Code automatically become a part of the State Rules, whereas in others they must first be adopted by the enforcement bodies.

Mr. Oatley recalled that following the last war there was much uncertainty in the quality of available materials and cautioned that vigilance in inspection would be required in the coming post-war period. This is particularly true because of the employment in many war materials of various alloying elements and these are likely to find their way, through scrap, into boiler steel. The Code, he observed, can never be considered a finished work, because of progress in the field.

Reciprocity between states in the issuance of reciprocal commissions to inspectors was proposed, to save time and travel expense of shop inspection by inspectors of the state in which a particular boiler is to be installed. It was suggested that this might be brought about by having all states and municipalities having enforcement regulations accept a National Board inspector's commission. In a few states this would involve changes in the existing laws or their interpretation. The consensus was that this is a matter which the National Board should get behind.

Among other subjects that came up for consideration at the meeting were procedures necessary before second-hand boilers or pressure vessels can be shipped into a state, adoption of recommended rules for repair by fusion welding, tolerance to be permitted in operation of non-standard boilers after the war emergency, major alterations of new boilers in the field, and the suggestion that Code requirements make it compulsory on large boilers to provide a dual source of drive for the feed pumps.

At the business meeting following the general sessions Gerald Gearon, who had been filling out the unexpired term of the deceased chairman, was elected chairman.

E. R. Fish Honored

At a dinner given by the A.S.M.E. Boiler Code Committee at the Engineers' Club, New York, on May 24, as host to the National Board of Boiler and Pressure Vessel Inspectors, Edward R. Fish, past chairman of the Boiler Code Committee, was presented with a scroll to commemorate his election as an Honorary Member of the National Board.

T. B. Allardice, of the American Gas & Electric Service Corporation, acted as toastmaster and addresses were made by H. B. Oatley, Chairman of the Boiler Code Committee; Gerald Gearon, Chairman of the National Board; and C. E. Davies, Secretary of the A.S.M.E., representing President Alex Bailey who was unable to be present. Ninety-three attended the dinner.

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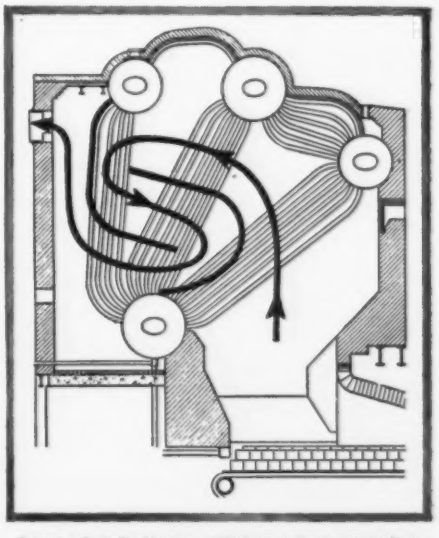

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Mobile Power Plants Furnished by British

Much has been published on the power trains built in this country and supplied under Lend-Lease to Russia for supplying emergency power to devastated regions and it may be of interest to review what the British have been doing along similar lines.

In the May 1945 issue of *Engineering and Boiler House Review* (British) a description is given of the mobile power plants supplied by the Metropolitan-Vickers Electrical Company Ltd., as prime contractor, to the Ministry of Supply for the Soviet Government. Many of these sets are already in service and more are being built or are in transit.

Mounted on railway cars, these units fall into four groups, namely, 1000-kw coal-fired, 1000-kw oil-fired, 2500-kw coal-fired and 5000-kw oil-fired. It will be recalled that the 5000-kw units for the power trains built in the United States are designed to burn low-grade coal or lignite.

The coal-fired boilers for the 1000-kw sets are of the John Thompson water-tube type with integral economizer and water-cooled furnace fired by a motor-driven chain-grate stoker. A belt conveyor delivers coal to the stoker hopper. Both forced and induced draft is provided. The maximum continuous output is 16,750 lb of steam per hour at 382 psig and 690 F total steam temperature.

Forced-Circulation Boilers Included

The oil-fired boilers for the 1000-kw sets are of the La Mont forced-circulation type built in two distinct sections, the first being the combustion-chamber cooling tubes and the second the boiler convection elements arranged in two banks to provide space for the superheater. The circulating pump is steam driven and boiler feed makeup is supplied from a single-effect evaporator. The maximum continuous rating is 17,500 lb per hr at 390 psig and 690 F.

Boilers for the 5000-kw units are of Foster-Wheeler design, manufactured under license by Ivor Power Specialty Company Ltd. They are of the two-drum bent-tube type, of 65,000 lb per hr maximum continuous rating at 392 psig and 700 F. Forced draft only is employed and the fan is driven by a single-stage impulse turbine. Boiler feed is condensate supplemented by makeup from a single-effect evaporator.

The turbine-generators for the several capacities are similar, except for the number of stages, in that they are all "Metrovick" geared units with the condensers built integral with the turbine exhausts.

In contrast with the American-built 5000-kw power trains which employed air condensers, the British-built units have conventional surface condensers designed for 27.6-in. vacuum with circulating water at 60 F.

The 5000-kw equipment is carried on three cars and the 2500-kw set on two—each exclusive of an additional car to handle miscellaneous equipment, spares and supplies. As a protection against weather each car is covered by canvas mounted on tubular supports.

Novel Wind Turbine

The Federal Power Commission has issued a staff report, prepared by Percy H. Thomas, presenting the preliminary results of a survey undertaken to determine the potentialities of the wind as a source of electric energy. The investigation was based on a study of the records of the Weather Bureau, which show wind-velocity readings taken at all times of the day and night and throughout the year at hundreds of stations scattered over the country.

The studies also show that the velocity of the wind increases with higher elevations above the earth's surface. While no consistent and complete data appear to exist from which a reliable determination of the relation of altitude to wind velocity can be obtained, the report says that it appears from the average of a considerable number of balloon observations that the wind velocity 500 ft from the surface will in a general way have a value from 1.35 to 1.45 times the velocity within 40 ft of the surface.

On the basis of his study Mr. Thomas has designed wind turbines with new and novel features and having considerably larger capacity than any existing at present. The designs are substantially different from the 1000-kw wind turbine installation of the Central Vermont Public Service Corp. atop Grandpa's Knob near Rutland, Vermont, which has been used for several years for the commercial generation of electric energy.

One of Mr. Thomas' designs is for a 7500-kw unit, and the other for a 6500-kw unit. The former provides for a twin-wheel layout with a turbine wheel mounted on each end of a 200-ft bridge. There are two airplane-type propeller blades per wheel. These require unusual bracing because of their great length, 100 ft, and the enormous aerodynamic bending stress, which is estimated at 42 tons per blade.

The 6500-kw design utilizes the same tower and has the same diameter wheel, but has three blades per wheel instead of two. In this design, the braces are placed on the windward side of the blades and are given appropriate cross-sections and prescribed blade angles so that they may act to develop power.

One of the most interesting features of the designs is that the blade units are fixed. Feathering, as in certain types of airplane propellers, has been omitted. The necessary control of the turbine speed to fit it to the existing wind velocity is secured by a differential device, operating, through a relay, on the field strength of the generator, acting to adjust continuously the load on the unit to that appropriate for the wind velocity of the moment. Powerful automatic brakes permit stopping the blades in case winds of hurricane velocity threaten to impose too great a load on them.

The Thomas designs for larger units appear to solve one of the most perplexing problems involved in the generation of electric energy by the wind, that of generating electricity from a wheel that revolves at varying speeds and sending it into a transmission system at standard and unvarying frequency. This is done by first-stage generation of direct current, which has no frequency, and converting it to al-

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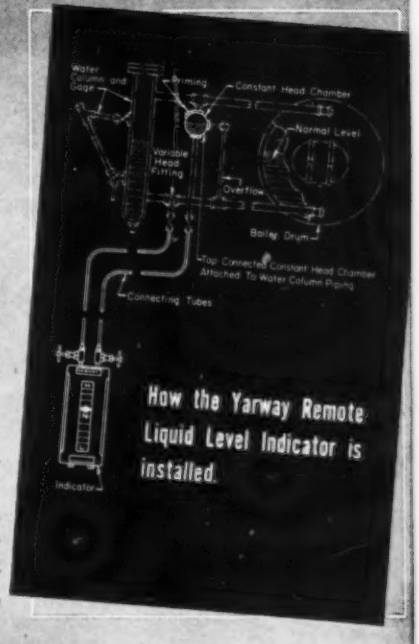
The Yarway Indicator is moderately priced and easily installed on new or existing equipment. (See diagram.) Over 2000 already in use . . . to indicate boiler and feed heater water level, also superheater pressure differential. For complete description, ask for Bulletin WG-1820.



How the Yarway Remote Liquid Level Indicator is installed.

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ternating current of the desired frequency. Although the amount of energy available for any one wind turbine may vary from hour to hour, the frequency of the energy will not.

Among the areas in which it would appear feasible to install wind turbines are the great wind-belt which extends from the Dakotas southward to Texas, and perhaps on islands located within trade wind belts. The report stresses the fact that the operation of wind turbines for utility purposes would be as an auxiliary source of power, but that it appears feasible as a source of energy in areas in which fuel supplies are sparse and hydroelectric energy is available to serve as a "storage battery" during periods when wind velocities are insufficient.

Under-Channel Oil Line

How American productive capacity and technical know-how aided the British government in the laying of twenty 3-in. oil pipe lines under the English Channel to supply Allied armies with oil soon after they landed on the Normandy coast, has been revealed here by engineers of General Electric, one of four American concerns that produced sizable quantities of the pipe involved.

The project of piping oil under the Channel to supply an Allied fighting machine doing battle on another continent was conceived by Lord Louis Mountbatten in April, 1942. Since then, the lines have carried an average of a million gallons a day, it was revealed in a report from Geoffrey Lloyd, Minister of the British Petroleum Warfare Department.

To American industrial plants which were given the momentous job of adding their great productive capacity to that of Britain, the project presented difficulties never before encountered. Average cables previously manufactured had an internal pressure of from 10 to 15 psi; the new line demanded pipes that could withstand pressures 1200 psi.

General Electric was given a contract to manufacture 20 miles of the new pipe line on March 3, 1944, and got into production on the project on June 1. Twelve days later the first shipment was ready to be sent overseas for installation. With more than 25,000 ft of the pipe included in each shipment, G.E. produced four shipments of the pipe. The last of these contracted for was completed on July 17 in only 10 days time, an average of more than 3000 ft per day.

Because the undersea pipe line was designed to withstand tremendous internal pressures, new methods of manufacture had to be set up on a moment's notice. A. C. Hartley, British engineer, who was instrumental in drawing up the original plans, came to America to collaborate with engineers here in reconverting their plants and retraining their technicians.

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BOOK REVIEWS

Building Insulation—2nd Edition

By Paul Dunham Close, B.S.

Here is a book to serve as a reference volume for those interested in the subject of heat and sound insulation for buildings. In this new edition an effort has been made to cover the subject in such a manner that it will be useful and of practical value to the architect or engineer, to the dealer, and to the consumer who may be contemplating the construction of a new house or the remodeling of an old one. A sincere effort has been made to avoid discrimination, to treat all products fairly and without bias and to state the facts as they are known.

The author is chairman of the A.S.H.V.E. Technical Advisory Committee on Heat Requirements of Buildings and for years has served as a member of the Publication Committee. We know of no one better qualified to compile such a treatise on the principles and application of heat and sound insulation.

The book contains 328 pages and includes 54 tables and 154 excellent illustrations and charts. It is fully indexed and bound in stiff washable cloth covers. Size $5^1/_4 \times 8^1/_4$. Price $3.50.

Heating, Ventilating and Air Conditioning Guide—1945

American Society of Heating and Ventilating Engineers

The 23rd Edition of the Guide published by the American Society of Heating and Ventilating Engineers contains 48 chapters of technical data and information pertaining to all phases of heating, cooling, ventilating and air conditioning. The chapter on Heating Boilers has been revised to include present accepted rating practice and includes clarified definitions of the various terms referring to heating load.

The new volume includes 808 pages of technical data; 344 pages of equipment data, and the Roll of Membership of the Society. The book retains its familiar size (6×9) and is bound in blue covers. Price $5.00.

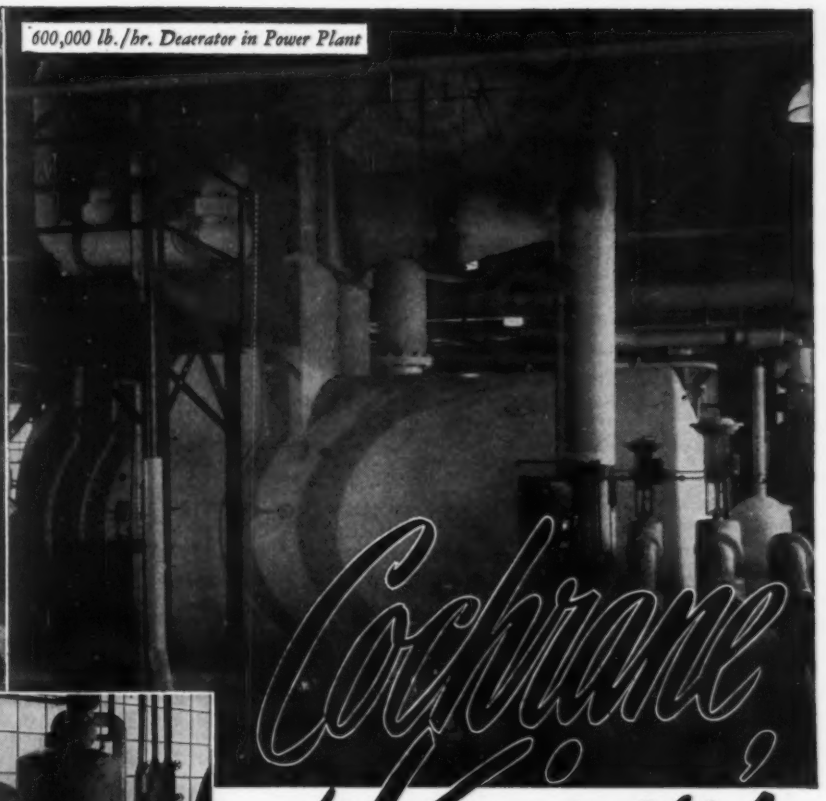
Manual of Instructions on Proper Firing Methods

Smoke Prevention Association of America, Inc.

This 72-page typescript manual comprises papers given before the Smoke Prevention Association of America, and is published for the benefit of the coal dealer and the coal consumer. Some of the topics covered include: Fuel Conservation; Furnace Turbulence; Fuel Oil and Its Combustion; Furnace Dimension Charts for Underfeed Stoker Installations.

The Manual is distributed on a complimentary basis to coal dealers and consumers who are interested in fuel conservation and smoke abatement. Copies may be secured on request when accompanied by postage (25 cents each) to cover the cost of mailing.

80,000 lb./hr. Deaerator in Open Hearth plant, showing provision for a second Deaerator on the storage tank. Also shown is Cochrane Multiport Relief Valve.



600,000 lb./hr. Deaerator in Power Plant

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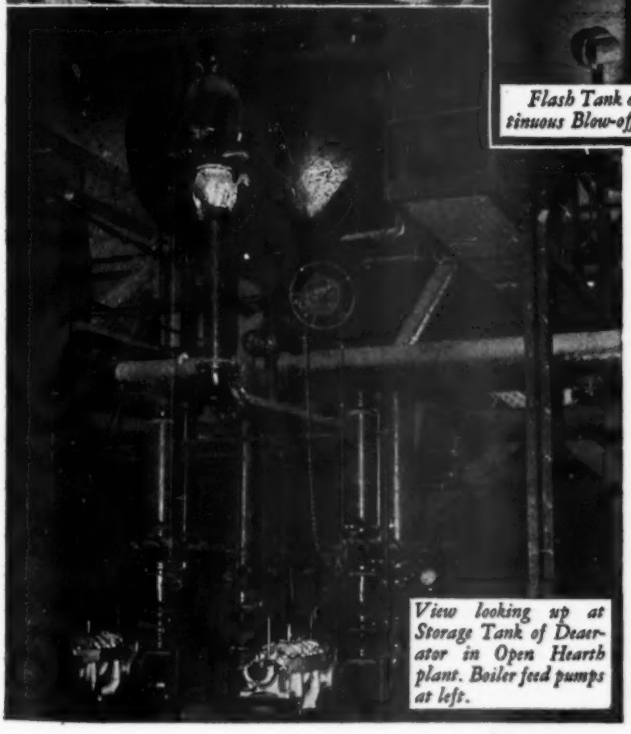
Flash Tank of Continuous Blow-off System.



View looking up at Storage Tank of Deaerator in Open Hearth plant. Boiler feed pumps at left.

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Noteworthy is the Cochrane 600,000 lbs./hr. Deaerator mounted on a horizontal cylindrical storage tank, delivering oxygen-free feed water to the boilers, which generate the steam supply for Coke Ovens, Blast Furnace, Open Hearth and Rolling Mills. Another Cochrane Deaerator of 80,000 lbs./hr. capacity is located in the basement of the Open Hearth plant supplying oxygen-free make-up to the boiler, in which is used the waste heat from the Open Hearth furnaces. This deaerator is mounted on a horizontal cylindrical storage tank, which has provision for mounting a second deaerator of equal size. A Cochrane Continuous Blow-off System serving 3 boilers is also installed in the Power Plant.

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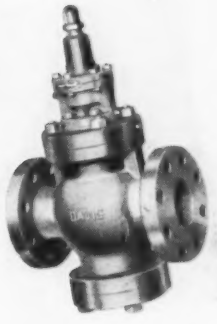

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